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1

2

3

4

5

6

7

8

9

10

11

12

13

14

15

16

17

18

19

20

21

22

23

24

25

26

27

28

29

30

31

32

33

34

35

36

37

38

39

40

41

42

43

44

45

46

47

48

49

50

51

52

53

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57

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71

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73

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107

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109

110

111

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115

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117

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129

130

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132

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136

137

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146

147

148

149

150

151

152

153

154

155

156

157

158

159

160

161

162

163

164

165

166

167

168

169

170

171

172

173

174

175

176

177

178

179

180

181

182

183

184

185

186

187

188

189

190

191

192

193

194

195

196

197

198

199

200

201

202

203

204

205

206

207

208

209

210

211

212

213

214

215

216

217

218

219

220

221

222

223

224

225

226

227

228

229

230

231

232

233

234

235

236

237

238

239

240

241

242

243

244

245

246

247

248

249

250

251

252

253

254

255

256

257

258

259

260

261

262

263

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266

267

268

269

270

271

272

273

274

275

276

277

278

279

280

281

282

283

284

285

286

287

288

289

290

291

292

293

294

295

296

297

298

299

300

301

302

303

304

305

306

307

308

309

310

311

312

313

314

315

316

317

318

319

320

321

322

323

324

325

326

327

328

329

330

331

332

333

334

335

336

337

338

339

340

341

342

343

344

345

346

347

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1914

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CONTENTS OF VOLUME XXIV

	Page
Title page.....	i
Officers	ii
Contents	iii
Dates of Publication and Editions of Brochures.....	iii
List of Illustrations.....	iv
The Use of Crinoid Arms in Studies of Phylogeny. By ELVIRA WOOD. (Plates I-V).....	1
Notes on <i>Camarasaurus</i> Cope. By C. C. MOOK.....	19
The Genesis of Antigorite and Talc. By ALEXIS A. JULIEN. (Plate VI) ..	23
A Study of the Changes in the Distribution of Temperature in Europe and North America During the Years 1900 to 1909. By HENRYK ARC- TOWSKI	39
The Genesis of Certain Paleozoic Interbedded Iron Ore Deposits. By RAYMOND BARTLETT EARLE. (Plates VII-XXI).....	115
Climate and Evolution. By W. D. MATTHEW.....	171
Development of the Neuraxis in the Domestic Cat to the Stage of Twenty- one Somites. By H. von W. SCHULTE and FREDERICK TILNEY. (Plates XXII-XLI)	319
Records of Meetings, 1914. By EDMUND OTIS HOVEY.....	347
The Organization of the Academy.....	407
The Original Charter.....	407
Order of Court.....	409
Amended Charter.....	410
Constitution	413
By-laws	414
Membership Lists, 31 December, 1914.....	421
Index	433

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LIST OF ILLUSTRATIONS

Plates

- I.—*Cactocrini*, Individual specimens.
- II.—*Cactocrini*, Details of plates.
- III.—*Cactocrini*, Details of plates.
- IV.—*Cactocrini*, Details of plates.
- V.—*Cactocrini*, Details of plates.
- VI.—Laminated Chrysotile-Asbestos from Thedford, Canada.
- VII.—Map showing the Distribution of Clinton Hematites in the United States.
- VIII.—Fossil Ore.
- IX.—Fossil Ore—Photomicrographs.
- X.—Oölitic Ore.
- XI.—Cavernous Consolidation.
- XII.—Special Consolidations.
- XIII.—Special Consolidations.
- XIV.—Partial Impregnation.
- XV.—Cherty Limestone Seams.
- XVI.—Fossil Ore—Photomicrographs.
- XVII.—Contact Specimens.
- XVIII.—Mud Cracks.
- XIX.—Contact Specimens.
- XX.—Contact Specimens.
- XXI.—Oölitic Ore—Photomicrographs.
- XXII.—Sections of Embryos before and after Segmentation.
- XXIII.—Sections of Embryos with Two and Three Somites.
- XXIV.—Transverse Section, Embryo of Four Somites.
- XXV.—Transverse Section, Embryo of Four Somites.
- XXVI.—Transverse Section, Embryo of Four Somites.
- XXVII.—Reconstruction of Neuraxis of Embryos of Four and Eight Somites.
- XXVIII.—Transverse Section, Embryo of Eight Somites.
- XXIX.—Transverse Section, Embryo of Eight Somites.
- XXX.—Transverse Section, Embryo of Eight Somites.
- XXXI.—Reconstruction of Neuraxis of Embryo of Nine Somites.
- XXXII.—Reconstruction of Neuraxis of Embryo of Ten Somites.
- XXXIII.—Reconstruction of Neuraxis of Embryo of Twelve Somites.
- XXXIV.—Reconstruction of Neuraxis of Embryo of Fourteen Somites.
- XXXV.—Reconstruction of Neuraxis of Embryo of Sixteen Somites.
- XXXVI.—Reconstruction of Neuraxis of Embryo of Seventeen Somites.
- XXXVII.—Reconstruction of Neuraxis of Embryo of Nineteen Somites.
- XXXVIII.—Reconstruction of Neuraxis of Embryo of Twenty-one Somites.
- XXXIX.—Reconstruction of Portions of Neuraxis of Embryos of Eight and Nine Somites.
- XL.—Reconstruction of Portions of Neuraxis of Embryos of Twelve and Twenty-one Somites.
- XLI.—Transverse Section of Embryo of Sixteen Somites.

Text Figures

	Page
Relationship of species of <i>Cactocrinus</i> and <i>Teleocrinus</i>	16
Restoration of <i>Camarasaurus</i> by Cope.....	21
Diagrams of consecutive annual and consecutive monthly means of temperature at Arequipa.....	43
Macropleion. 1878-1887	47
Macropleion. 1879-1888	47
Macromeion. 1880-1889	47
Macromeion. 1881-1890	47
Macropleion. 1893-1902	48
Macropleion. 1894-1903	48
Macropleion. 1895-1904	48
Macropleion. 1896-1905	48
Curves of the consecutive means at Bucharest, Odessa, Warsaw, Kazan and Arequipa	62
Consecutive temperature curves at Geneva, Aachen, Vestervig, Bodö, Haparanda and Sydvaranger.....	63
Temperature departures for the year 1900.....	66
Temperature departures for the year 1901.....	66
Temperature departures for the year 1902.....	67
Temperature departures for the year 1903.....	67
Temperature departures for the year 1904.....	69
Temperature departures for the year 1905.....	69
Temperature departures for the year 1906.....	70
Temperature departures for the year 1907.....	70
Temperature departures for the year 1908.....	72
Temperature departures for the year 1909.....	72
Temperature departures for the year 1900.....	80
Temperature departures for the year 1901.....	80
Temperature departures for the year 1902.....	81
Temperature departures for the year 1903.....	81
Temperature departures for the year 1904.....	83
Temperature departures for the year 1905.....	83
Temperature departures for the year 1906.....	84
Temperature departures for the year 1907.....	84
Temperature departures for the year 1908.....	86
Temperature departures for the year 1909.....	86
Successive positions of the quasinormal line.....	89
Progressive displacements of the antipleion of 1901.....	89
Displacements of the quasinormal line.....	90
Departures of temperature averages for October, 1902,-September, 1903..	90
Departures of temperature averages for November, 1902,-October, 1903...	90
Departures of temperature averages for December, 1902,-November, 1903.	90
Departures of temperature averages for February, 1903,-January, 1904...	91
Departures of temperature averages for March, 1903,-February, 1904.....	91
Departures of temperature averages for April, 1903,-March, 1904.....	91
Departures of temperature averages for May, 1903,-April, 1904.....	91
Departures of temperature averages for March, 1904,-February, 1905.....	92
Departures of temperature averages for July, 1904,-June, 1905.....	92

Text Figures—Continued

	Page
Departures of temperature averages for January–December, 1905.....	92
Departures of temperature averages for February, 1905,–January, 1906....	92
Departures of temperature averages for January–December, 1906.....	93
Departures of temperature averages for February, 1906,–January, 1907....	93
Departures of temperature averages for April, 1906,–March, 1907.....	93
Departures of temperature averages for June, 1906,–May, 1907.....	93
Displacements of the quaslnormal line on the consecutive departure maps of February, 1907,–January, 1908, until July, 1907,–June, 1908.....	94
Pleionian pendulations	96
Pleionian amplitudes and the Arequipa curve.....	96
Consecutive temperature curves of Atlantic coast stations.....	98
Temperature variation of Montana (Miles City) compared with that of Maine (Eastport)	100
Temperature variations in Montana, Nebraska, Kansas and Louisiana....	101
Comparison of variations in California and Texas with the Arequipa curve	102
Temperature variations in Greenland, Iceland and Faroe.....	105
Temperature variations in Newfoundland and Maine.....	107
Temperature variations in the Azores, Madeira and Cape Verde Islands..	108
Temperature curves at St. Helena, Arequipa, Porto Rico and Bermuda...	109
Pleionian connections	112
Zoölogical regions on north polar projection.....	174
The southern continents, south polar projection.....	176
Cross-section of continental platforms and ocean basins at 45° north lati- tude	177
Cross-section of continental platforms and ocean basins at the equator....	177
Characteristic features of the mammal faunæ in different zoölogical re- gions at successive epochs of the Cenozoic.....	187
Dispersal and distribution of the principal races of man.....	210
Dispersal of the Primates.....	214
Phylogenetic relations of the living and extinct groups of Primates.....	215
Distribution of modern Canidae.....	217
Distribution of the Procyonidae and Viverridae, formerly Nearctic and Palæarctic, but now surviving chiefly in the peripheral regions.....	220
Distribution of the Ursidae, Pleistocene and Recent.....	222
Distribution of Soricidae and of Talpidae.....	225
Distribution of Geomyoidea, Anomaluridae and Pedetidae.....	229
Distribution of the true Porcupines (Hystriidae) and New World Porcu- pines (Erethizontidae)	230
Distribution of the Neotropical families of Hystricomorphs.....	232
Dispersal and distribution of the Perissodactyla.....	234
Distribution of Equidae, living and Pleistocene.....	235
Geologic range and phylogenetic relations of fossil Equidae.....	236
Distribution of the Tapirs, living and Pleistocene.....	238
Distribution of the Rhinoceroses, living and Pleistocene.....	239
Distribution of Pigs and Peccaries.....	241
The dispersal center of the Camelidae was in North America.....	243
Distribution of Cervidae and pro-Cervid Tragulidae.....	245

Text Figures—Continued

	Page
Distribution of the Bovidæ, existing and extinct.....	248
Distribution of the Giraffes, existing and extinct.....	249
Distribution of the Anthracotheres and Hippopotami.....	252
Phylogeny and distribution of the Artiodactyla.....	254
Relationship of the Condylarthra to the Notoungulate and Subungulate groups of hoofed mammals.....	257
Distribution of the Edentate orders.....	259
Distribution and phylogeny of Xenarthra and Tæniodonta.....	260
Distribution of Marsupials.....	263
Distribution of the Crocodilidae.....	285
Distribution of three families of Anura.....	296
Schema of the composition of the encephalon in terms of basal and alar plates of His.....	338
Schema of the composition of the encephalon in terms of basal and alar plates and ganglionic zone.....	339

THE USE OF CRINOID ARMS IN STUDIES OF PHYLOGENY¹

BY ELVIRA WOOD

(Presented by title before the Academy, 2 March, 1914)

CONTENTS

	Page
Introduction	1
Description of <i>Cactocrinus</i> and six species of the genus.....	3
Comparison of the preceding six species.....	9
The <i>Cactocrinus multibrachiatus</i> series.....	12
Comparison of the preceding three species.....	14
Relation of <i>Cactocrinus</i> to <i>Teleocrinus</i>	15
Conclusion	17

INTRODUCTION

In studying the phylogeny of Paleozoic crinoids, the worker is greatly hampered by the difficulty of obtaining information about the early stages in ontogeny. By the time the young crinoid is sufficiently calcified to be preserved in the fossil state, the calyx has nearly, if not quite, all the plates which are to be present in the adult. This fact is illustrated by a calyx of *Batocrinus subæqualis* only 4 millimeters in height which possesses all the plates of the adult, with the full number of arms and a well-developed tegmen and anal tube. The present paper is concerned with results which were obtained from a study of adult, or of late neanic stages of camerate crinoids.

In order to determine the exact amount and character of the variation occurring in the number and arrangement of calyx plates, about one hundred specimens of *Batocrinus* and *Cactocrinus* were examined and the position of each plate carefully recorded. From this investigation, it was found that there is very little variation in the plates concerned in the support of the arms. In the specimens of *Cactocrinus* examined, the only variation in the radial series was found to be due to the presence of an extra arm or one arm less than the normal number for the ray, necessitating a greater or smaller number of plates in the calyx. In each case, the plates present followed the normal order for a similar ray or half ray

¹ Manuscript received by the Editor, 4 February, 1914.

in another species. In *Batocrinus*, the most frequent variation in the radial series was due to the absence of the first costal, or rarely, to the presence of an extra distichal below the axillary one. A greater amount of variation occurs in the number of interbrachials, as these are simply space fillers, and their number depends mainly on the relative height and width of the cup. The most marked variation was found in the anal area. Of the seventy-five specimens of *Batocrinus* studied, four had two plates in the second row of the anal series, as in the Actinocrinidæ, and one of twenty-five specimens of *Cactocrinus* had three plates in the second row, after the manner of the Batocrinidæ. As will be readily seen, this amount of variation furnishes little evidence which can be used for working out phylogeny, except in the most general way.

The ornament on the surface of closely related species differs in degree rather than in kind, and hence does not show changes sufficiently definite to furnish satisfactory results.

The stems of crinoids often show very definite and well-marked changes from the proximal to the distal portion, but it is so comparatively rare to find the crinoid stems intact for any considerable distance from the calyx that they are only occasionally helpful.

A study of crinoid arms has shown that in some genera, at least, more satisfactory results may be obtained. It has long been recognized that the uniserial condition at the base of many arms which later become biserial is reminiscent of ancestral species whose arms were uniserial throughout. Applying the same principle to other characters, it is believed that changes in the form and ornament of the arm are indications of changes through which the ancestors of a species have passed and that, taken in connection with other characters, they may be used to determine the phylogeny of the group to which the species belongs. This method of study will obviously be most useful in genera having highly modified arms, and the genus *Cactocrinus* has furnished the material upon which the present paper is based. No single character can be used alone in working out relationship, and in this study constant reference has been made to the characters of the calyx as well as of the arms. The columns, in nearly all the specimens available for study, were not preserved.

In the descriptions of species of *Cactocrinus* which follow, a reference is given to the original description and to a later full description and figures. Only such facts are added here as have a bearing upon the present investigation, except in the case of new species and *Cactocrinus proboscidalis*, which may be used as a standard of comparison for other species and is fully described.

DESCRIPTION OF CACTOCRINUS AND SIX SPECIES OF THE GENUS

Cactocrinus Wachsmuth and Springer

1897. *Cactocrinus* WACHSMUTH and SPRINGER, North American Crinoidea
Camerata, p. 600.

The species included in the genus *Cactocrinus* were, with few exceptions, originally described under the genus *Actinocrinus*, and for the present purpose, the genus is sufficiently defined by enumerating the features by which it is distinguished from *Actinocrinus*. The most noticeable of such distinguishing characters seems to be the arrangement of the arms, which form a more or less continuous row around the calyx; that is, the interbrachial and interambulacral plates do not meet between the arms as is the case in *Actinocrinus*. Another distinguishing feature is that, in species having more than four arms to the ray, the third bifurcation takes place on the second or third plate above the distichals in *Actinocrinus*, while the axillary palmar immediately follows the axillary distichal in *Cactocrinus*. The two genera are also said to differ in the structure of the pinnules, but the spines on the proximal pinnules of *Cactocrinus* are represented also on many species of *Actinocrinus*, as well as on other genera as far removed as *Dorycrinus* and *Eretmocrinus*. Hence this cannot be used as a distinctive feature.

The type of the genus is *Cactocrinus proboscidalis* (Hall).

Cactocrinus proboscidalis (Hall)

Plate I, fig. 1; plate II, figs. 1, 2, 2a, 2b

1858. *Actinocrinus proboscidalis* Hall, Rept. Geol. Surv. Iowa, Vol. 1, pt. 2, p. 584, pl. 10, fig. 13.

1897. *Cactocrinus proboscidalis* Wachsmuth and Springer, North American Crinoidea Camerata, p. 601, pl. 58, figs. 3, 4, 5, 6, 7 a-d.

The calyx of this species has a width slightly greater than its height. There are, as usual in the genus, three basals, five radials and five each of first and second costals. The axillary distichals rest directly upon the second costals, and each of these gives rise to two arms, making four to the ray. The surface of the calyx is ornamented by a node at the center of each plate from which simple carinæ radiate across the margins and become continuous with the carinæ from adjacent plates. The entire surface of both cup and arms is covered with extremely fine granules.

The arms are long, three or four times the height of the calyx. Beyond the first palmars, from one to three plates pass entirely across the diameter of the arm, hence the biserial condition is attained early in this

species. In form, the arms are cylindrical at the base, but at a distance from the base varying from the third to the tenth plate, they become flattened laterally, and the individual plates are elongated, producing a marked expansion of the arm at about half its height which may be taken to represent the adult stage. Beyond this, the arm tapers gradually to a point, at the same time becoming more nearly circular in cross section than at its middle portion. In the growth of the crinoid arm, new plates are formed at the tip, and these small, nearly cylindrical plates are in an immature condition. Their resemblance in form to the plates near the base of the arm probably indicates that they are passing through a stage comparable to an early stage in the development of the entire arm. That such localized stages occur in other genera has already been pointed out by Grabau.²

Immature plates were observed only in *Cactocrinus proboscidalis* and *C. baccatus*. Others of the species studied had the arms strongly incurved and the tips concealed by the matrix, except in the *C. multi-brachiatus* series where the arms were imperfect at the ends.

Each plate of the arm of *C. proboscidalis* bears a distinct transverse ridge running the entire width of the plate and situated about one-third of its height from the upper margin. The ornament appears on early plates, at distances from the base differing somewhat in different specimens, and continues to the extreme tip of the arm. The proximal pinules, as in other species of the genus, bear strong overlapping spines.

Column cylindrical. The proximal nodals project but slightly beyond the internodals, but at a distance of about 20 millimeters from the calyx, the nodals have twice the diameter of the internodals and have their margins extended into a thin, knife-like edge. At a distance of 85 millimeters from the body, the number of intercalated plates has increased until there are seven between successive nodals, and at this point the nodals have blunt margins projecting but little beyond the internodals.

Tegmen moderately high, covered with numerous nodose plates. Anal tube long and slender.

HORIZON AND LOCALITY: Lower Burlington limestone, Burlington, Iowa. No. 415, Museum of Comparative Zoölogy collection.

Cactocrinus baccatus sp. nov.

Plate I, fig. 3; plate II, figs. 3, 4, 4a, 4b

Calyx similar to that of *Cactocrinus proboscidalis* in form. Basals variable in size, sometimes minute with the calyx resting upon the radials, sometimes as large as in *Cactocrinus proboscidalis*.

² A. W. GRABAU: Amer. Jour. Sci., 4th ser., Vol. 16, pp. 289-300. 1903.

In arrangement of the plates and surface ornament, this species does not differ essentially from *C. proboscidalis*, there being the usual number of plates, five basals, five each of radials, first and second costals and ten axillary distichals each of which bears two arms, making four to the ray. The arms of the two species are similar in form, being cylindrical at the base, strongly flattened laterally throughout the greater portion of their length, tapering and becoming more nearly cylindrical near the tips. The most characteristic difference is in the ornament of the arms, for while the arm plates of *C. proboscidalis* bear a single transverse ridge throughout, the arms of *C. baccatus* have this simple ridge only near the base of the arm. At a distance from the base varying from 6 to 20 millimeters in different specimens and varying to some extent in different arms of the same specimen, the transverse ridge is broken up into a row of small nodes of which there are five or six on each plate at the greatest diameter of the arm.

The column was not preserved with any of the specimens found.

HORIZON AND LOCALITY: Lower Burlington limestone, Burlington, Iowa. No. 558, Museum of Comparative Zoölogy collection.

Cactocrinus platybrachiatus, sp. nov.

Plate I, fig. 2; plate III, figs. 1, 2, 2a, 2b

The basals of the only specimen representing this species are not preserved. Of the plates above the radials, only those of two rays and one interradiar area are preserved. Their arrangement seems to be the same as that usual in the genus for five or six armed rays; that is, in one of the half-rays present, the axillary distichal is followed, without intervening plates, by an axillary palmar which gives rise to two arms. The palmar resting on the other axillary face of the distichal bears one arm giving three arms to this half ray. The same arrangement is seen in another half ray, but whether there were two or three arms in the other half of the same ray cannot be determined. There is one small interdistichal, and the formula for the interbrachials is 1, 2, 2, 1.

The ornament on the calyx is essentially the same as that of *Cactocrinus proboscidalis*, but since there are more plates due to the greater number of arms, and a ridge crosses each suture line between the plates, the costæ appear more crowded than on the latter species. The node at the center of each plate is also less prominent.

The arms are cylindrical near the base but expand rapidly in the median portion. They are flattened laterally but less strongly so than the arms of *Cactocrinus baccatus*. The form of the arms changes gradually, until in the upper portion they are flattened dorso-ventrally. Their tips are incurved toward the anal tube and buried in the matrix. The biserial condition is attained early, only one or two plates at the base passing entirely across the arm. The surface of the arm is smooth at the base. A little later a transverse ridge appears which soon breaks up into a row of nodes like those of *Cactocrinus baccatus*. This type of ornament persists for the greater portion of the length of the arm, but by the time the dorso-ventral flattening is established, some of the lateral nodes become confluent, reducing their number until there are but three on each plate, and on some of the latest plates visible, there are

only two, a shorter node near the median line of the arm and an elongated one placed laterally.

The column is unknown.

HORIZON AND LOCALITY: Lower Burlington limestone, Burlington, Iowa. No. 568, Museum of Comparative Zoölogy collection.

Cactocrinus platybrachiatus is distinguished from *C. baccatus* by the greater number of arms, the dorso-ventral flattening of the arms and the confluence of their surface nodes in the upper part of the arm, probably representing a late stage of development. It is distinguished from *C. reticulatus* by the many nodes on the arms at the maximum differentiation in structure, representing the adult stage, the less strongly flattened arms and the absence of lateral spines on the arms near their tips.

***Cactocrinus reticulatus* (Hall)**

Plate III, figs. 3, 4, 4a, 4b, 4c

1861. *Actinocrinus reticulatus* Hall, Description of New Species of Crinoidea, Preliminary notice, p. 2.

1897. *Cactocrinus reticulatus* Wachsmuth and Springer, North American Crinoidea Camerata, p. 605, pl. 58, figs. 2a, 2b.

The arrangement of the calyx plates in this species is somewhat variable, owing to the fact that it has sometimes five and sometimes six arms to the ray. Of six specimens selected at random, three had 28 arms, one 27, one 24 and one 22 arms. When there are five arms to the ray, it is always one of the median palmars which is axillary and bears two arms, while with six arms to the ray, both median palmars become axillary and the lateral palmars bear a single arm. On the calyx of large individuals, the primary costæ are sometimes bordered by a second series producing a smaller triangle within a larger one. The nodes at the centers of the plates are inconspicuous or sometimes absent.

In form, the arms are cylindrical at the base, but soon their plates are elongated as in *Cactocrinus proboscidalis* (see Plate II, fig. 1). A little later, the plates are curved, forming an arm equal in lateral and dorso-ventral diameters. At a slightly higher point, the arms are flattened dorso-ventrally, and the latest of the exposed plates are strongly flattened in the same direction. The ornament begins on the early plates of the arm as a strong transverse ridge or elongate node near the lateral margin, and a few plates later, a new node appears near the median line of the arm. As growth continues, these two nodes appear on successive plates nearer and nearer to the lateral margin, and when they have receded far enough to leave a plain space near the median line, a new node appears in

that position. This node continues to increase in size at the same time that the lateral node diminishes. Later, as the arm approaches its dorso-ventrally flattened form, the lateral node disappears, the former median node is elongated into a projecting spine and the newly introduced median node is now a prominent feature of the ornament. The remainder of the arm is incurved and buried in the matrix, hence the character of the latest formed plates is unknown.

The column is not preserved on any of the specimens at hand.

HORIZON AND LOCALITY: Lower Burlington limestone, Burlington, Iowa. No. 527, Museum of Comparative Zoölogy collection.

***Cactocrinus denticulatus* Wachsmuth and Springer**

Plate IV, figs. 1, 1a, 2, 2a, 2b

1897. *Cactocrinus denticulatus* Wachsmuth and Springer, North American Crinoldea Camerata, p. 606, pl. 57, figs. 5a, 5b.

Cactocrinus denticulatus is closely related to *C. reticulatus*. The arrangement of the calyx plates is the same, except that in *C. denticulatus* six arms to the ray form a constant feature necessitating a greater number of plates for their support. The ornament is somewhat more elaborate from the fact that small nodes are present on the costæ of the upper part of the calyx, and these sometimes extend as irregularly placed nodes over the base of the arms.

The arms pass through the same series of changes in form as those described for *Cactocrinus reticulatus*, except that the early condition with elongate plates is not present, and the successive changes up to the dorso-ventral flattening appear at a relatively earlier period in the development of the arm than in the preceding species. The latest exposed plates of the arm have a more extreme form than the corresponding plates of *C. reticulatus*. They are more strongly flattened dorso-ventrally, have longer spines, and the nodes are so high and pointed that, in some specimens, they might almost be called spines. Still further differences appear in the lateral spines, which are often alternately longer and shorter, and when this is the case, the nodes also alternate in size, the larger node occupying the plate with the shorter spine. This alternation in size of the spines and nodes is not perfectly regular, but it is a pronounced tendency which manifests itself to some extent on all the specimens studied. The nodes are not, as in the preceding species, close to the median line but have receded to some distance from it.

The column is missing from all the specimens studied.

HORIZON AND LOCALITY: Lower Burlington limestone, Burlington, Iowa. No. 534, Museum of Comparative Zoölogy collection.

Cactocrinus opusculus (Hall)

Plate I, fig. 4; plate IV, figs. 3, 4, 4a, 4b, 4c, 4d

1860. *Actinocrinus opusculus* Hall, Suppl. Geol. Rept. Iowa, see description of pl. 2.

1897. *Cactocrinus opusculus* Wachsmuth and Springer, North American Crinoida Camerata, p. 607, pl. 56, figs. 5a, 5b.

The calyx of this species bears a close resemblance to that of *Cactocrinus reticulatus*, except in the greater number of plates necessary for the support of six arms to the ray, which is the normal number for *C. opusculus*. The surface of the calyx is ornamented by a single node at the center of each plate with connecting carinæ, as in *C. reticulatus*.

At the base, the arms are, as usual in the genus, cylindrical and smooth, but they soon become flattened laterally, as in *C. proboscidalis*, and in retarded specimens bear the strong transverse ridge on the arm plates characteristic of that species. One specimen retains the *C. proboscidalis* type of ornament for 25 or 30 plates, while in accelerated individuals this condition is represented by only 2 or 3 plates, or may be absent altogether. In average individuals, at a distance from the base varying from the tenth to the twentieth plate, a slight angulation appears on the arm near the median line. This slight elevation increases in size on succeeding plates until it forms a distinct node. At the same time, it recedes farther and farther from the median line. The lateral node continues to increase in prominence until it becomes a distinct spine, and accompanying this change in the node, and partly in consequence of it, the form of the arm changes until it is strongly flattened dorso-ventrally. Meanwhile, another row of nodes has come in close to the median line on each side, as in *Cactocrinus reticulatus*. At the highest point observable the arm is strongly flattened dorso-ventrally with a row of spines along each lateral margin and a row of nodes on each side of the median line.

From the time the angulation appears until it develops into a distinct node, the surface of the plates is distinctly corrugated, although the strength of the corrugation varies greatly in different specimens. The specimen figured in Plate I, fig. 4, and Plate IV, fig. 3, is a highly accelerated individual showing all the characters at the acme of their development.

HORIZON AND LOCALITY: Lower Burlington limestone, Burlington, Iowa. No. 523, Museum of Comparative Zoölogy collection.

COMPARISON OF THE PRECEDING SIX SPECIES

A study of the first five of the species just described shows a series of gradations in structural characters which is here interpreted to mean that they form a continuous phylogenetic series in which the tendency of evolution has been from the simpler forms to the more complex.

Throughout the comparisons which follow, changes in structural features are assumed to represent stages in development, and the complete series of such changes to express the evolution of the arm as a whole.

The calyces from *Cactocrinus proboscidalis* to *C. denticulatus* show a progressive increase in the number of features to be considered. The greater number of calyx plates is due to the increase in the number of arms developed, from four in *C. proboscidalis* to six in *C. denticulatus*. The elaboration of surface features is expressed in additional carinae and fine nodes covering them in *C. denticulatus*.

The arms furnish more conclusive evidence of relationship. In studying the arms of crinoids, we have to consider several distinct characters, such as the stage at which the biserial condition is introduced, the form of the arm as expressed in its transverse section, the thickness of the individual plates and the surface features or ornament of the arms. Each of these characters may develop at a different rate of evolution in different specimens or even in different arms of the same specimen, but in the same phyletic series new features for each will appear in the same order but not, as already stated, necessarily at the same time. For example, we may find in one arm of *Cactocrinus denticulatus* the median row of nodes well developed on the twenty-fifth plate, while in another arm they are not distinct until the thirty-fifth. The lateral row of nodes may be developed on the sixth plate or not until the fifteenth plate, but the median row never appears before the lateral row.

Comparing the arms of the five species in detail, we find that *Cactocrinus proboscidalis* has a laterally flattened arm with simple transverse ridge. *C. baccatus* retains the same form and, according to the interpretation of the facts here given, passes through the same early stages as its ancestor, *C. proboscidalis*; that is, first cylindrical, then laterally flattened with a transverse ridge on each plate, but this species goes a step farther in the breaking up of the transverse ridge into a row of nodes. In both these species, the arms taper to a point. The arms of *C. platybrachiatus* pass through the same early stages as its ancestors, repeating the transverse ridged stage of *C. proboscidalis*, the nodose stage of *C. baccatus* and adding a feature of its own in the confluence of the nodes at a late stage of development. In form, the arms present entirely new features in their

expansion near the point of curvature and their dorso-ventral flattening. In the arms of *C. reticulatus*, the stage of the cylindrical smooth arm is followed by one in which each plate bears a short prominent ridge near the lateral margin which is believed to represent the confluent nodes of its ancestor, now reduced to one elongate node, or short ridge, placed close to the lateral edge of the plate. A few plates later, a small node appears near the median line. This stage is represented on Plate III, fig. 3. In successive plates of the arm, these two nodes appear nearer and nearer to the lateral margin until a plain space is left into which a new row of nodes is introduced near the median line. The median nodes increase in strength, while the outer ones diminish in size as they recede toward the lateral margin until they disappear. Meanwhile, the form of the arm has changed, becoming flattened dorso-ventrally so that the former median node occupies the lateral margin and is elongated into a spine. The line of nodes of latest origin remains near the median line. These changes are illustrated on Plate III, figs. 3, 4, 4a-4c. It thus appears that, in this group at least, new features arise near the median line of the arm and on successive plates seem to move laterally until they disappear and are replaced by features of later origin. This fact has led to the conclusion, stated above, that the elongate node on early plates of *Cactocrinus reticulatus* represents confluent nodes in a late stage of their evolution and soon to disappear, rather than that it has any relation to the transverse ridge present in early stages of its predecessor, *C. platybrachiatus*. The smooth space thus left on the median half of the plate, in the preceding species, becomes a field for the introduction of new features which appear successively as lines of nodes.

In the arm of *C. denticulatus*, the earliest stage to appear is that with an elongate node and a shorter one, both near the lateral margin of the plate. The ancestral features are, in this species, somewhat obscured by the presence, on early plates, of nodes which are the continuation over the base of the arms of the irregularly placed nodes present on the calyx of this species. They constitute a feature of later origin quite distinct from the two nodes near the lateral margin of the arm plates. These irregularly placed nodes are present only on early plates of the arm, and by the time the eighth plate is reached, they have disappeared, as shown on Plate IV, fig. 1. The two nodes remaining after the disappearance of the irregularly placed nodes are, in the specimen figured, sharply pointed, but this is not a constant feature for the species. Beyond this point, the evolution of the arm for the greater portion of its length is the same as that described for *C. reticulatus*, except that it is more accelerated, new features appearing at an earlier period than in the latter species. The

final stage in the evolution of the arm of *C. denticulatus* is more extreme than that of *C. reticulatus* in that the arms are more strongly flattened, the spines are longer and there is an alternation in the size of both spines and nodes. The lateral movement of surface features is further illustrated in this species by the fact that on the latest plates observable, the line of nodes last introduced does not remain near the median line as on *C. reticulatus* but has receded to some distance from it.

This series of five species of crinoids appears to constitute an excellent illustration of the principle of recapitulation, each member repeating the life history of its ancestor until, in the later members, early stages are crowded out of the ontogeny to be replaced by characters of later origin.

Cactocrinus opusculus, the sixth of the species described above, bears a strong general resemblance to *C. reticulatus*, but it has always six arms to the ray and consequently more plates in the calyx. The arms at the latest stage observable are closely similar to those of *C. reticulatus* at the same stage, but they have arrived at this condition along a different path from that traversed by the latter species, as shown by a comparison of the figures on Plate IV, fig. 3, with those on Plate III, fig. 3. The early stages lack the strong lateral node seen on *C. reticulatus*, and there is no indication in the ontogeny of the species that it has passed through the stage with rows of nodes present on *C. baccatus* and *C. platybrachiatus*. *C. opusculus* seems to have been descended from *C. proboscidalis* but as a lateral branch, following a different line of evolution from that of the *C. reticulatus* series. The resemblance between the final stages in the arms of *C. opusculus* and *C. reticulatus* may be considered a case of parallelism.

Another line of evolution from *C. proboscidalis*, divergent from that of the *reticulatus* series, is represented by *C. clarus*. This species closely resembles *C. proboscidalis* in the calyx and in the strong lateral flattening of the arms, but it is a much larger species and has five or six arms to the ray. The arms have on their early plates a transverse ridge which is strong near the lateral margin and is faint or absent near the median line. On successive plates this ridge becomes shorter and shorter, *i. e.*, apparently moves laterally on the arm like the nodes of *C. reticulatus* until, between the thirtieth and fiftieth plates, it disappears altogether, and the arm plates are smooth. These facts are here interpreted to mean that *C. clarus* is descended from *C. proboscidalis* but diverges from other lines of descent in the direction of loss of the ornamental feature represented by the transverse ridge.

Having followed certain lines of descent from *Cactocrinus proboscidalis*, it would be interesting to trace its ancestry, but I have, as yet, seen

no specimen which seems to fulfil all the requirements for such an ancestor. We may, however, reasonably infer what were some of its characteristics. The arrangement of the calyx plates was probably the same as that of *C. proboscidalis*, and the plates were nodose, either with or without connecting carinæ. The arms were cylindrical, smooth, tapering at the tips and the biserial condition was attained late, i. e., more than two or three plates passed entirely across the diameter of the arm. Such an ancestor would be expected to occur in strata older than those containing *C. proboscidalis*, and we should naturally look for it in the Kinderhook, but the species of *Cactocrinus* recorded from the Kinderhook, *C. nodobrachiatus*, *C. ornatissimus* and *C. arnoldi*, have ornamented arms of a type quite different from those of *C. proboscidalis* or any of its descendants. This indicates that the ancestor of *Cactocrinus* must have lived at a period considerably earlier than the Kinderhook.

Cactocrinus thetis, of the Lower Burlington, has arms which in form and surface are like those of the hypothetical ancestor of *C. proboscidalis*, but they are biserial almost from their point of origin, and there are six arms to the ray, while *C. proboscidalis* has but four. *C. thetis* was probably descended from the same ancestor as *C. proboscidalis*, but while the latter has developed in the direction of surface ornament and modification in the form of the arms, *C. thetis* has been retarded in surface ornament and has advanced in the direction of number of arms and in the early attainment of the biserial condition. The two species represent divergent lines of evolution.

Another species of *Cactocrinus* which probably occupies a relation to *C. proboscidalis* similar to that of *C. thetis* is *C. thalia*. The latter species has long, slender, cylindrical, smooth arms, only four to the ray, but it does not seem to be an ancestor of *C. proboscidalis*, since it is a larger species with longer and more slender arms which become biserial at an early stage.

CACTOCRINUS MULTIBRACHIATUS SERIES

***Cactocrinus multibrachiatus* (Hall)**

1858. *Actinocrinus multibrachiatus* Hall, Rept. Geol. Surv. Iowa, p. 580, pl. 10, fig. 10.

1897. *Cactocrinus multibrachiatus* Wachsmuth and Springer, North American Crinoidea Camerata, p. 617, pl. 56, figs. 6, 7; pl. 58, fig. 8.

The calyx of this species resembles that of *C. proboscidalis* except in the greater number of plates necessary for the support of eight arms to the ray, this being the normal number for the species, although a smaller

number is frequently present. The post-palmars, palmars and axillary distichals rest one upon another without intervening plates, following the usual plan in the genus *Cactocrinus*. The nodes at the centers of the plates are not prominent, and the costæ are simple, except on the lower half of the radials, where there are sometimes two or three passing to the basals.

The arms are long and slender, tapering very gradually to the tips and but slightly incurved. They are cylindrical for a distance of about twenty to thirty plates from the base and then become somewhat flattened dorso-ventrally, developing an obtuse angulation along the lateral margin. At about half their length, the arms are somewhat expanded laterally, and at this point or a little higher, they develop a narrow transverse ridge close to the upper margin of each plate. These ridges give the arm an appearance of being serrated along its lateral margin with each plate slightly inset above its predecessor. The arm of *C. multibrachiatus* is well represented by the figures of *C. cælatus spinotentaculus* on Plate V, fig. 1, except that it is all on a smaller scale.

HORIZON AND LOCALITY: Lower Burlington, Burlington, Iowa. No. 548, Museum of Comparative Zoölogy collection.

***Cactocrinus cælatus* var. *spinotentaculus* (Hall)**

Plate V, figs. 1, 2, 2a

1860. *Actinocrinus spinotentaculus* Hall, Suppl. Geol. Rept. Iowa, p. 86.

1897. *Cactocrinus cælatus* var. *spinotentaculus* Wachsmuth and Springer, North American Crinoidea Camerata, p. 619, pl. 59, fig. 10.

This species is closely similar to the preceding, except that it is much larger and the calyx is proportionally higher. The proportion of height to width in *C. cælatus* var. *spinotentaculus* is about $1:1\frac{1}{7}$ as compared with $1:1\frac{1}{2}$ in *C. multibrachiatus*.

In arrangement of plates and surface ornament, the two species are the same. The arms are eight to the ray and so similar to those of *C. multibrachiatus* that the same drawing serves to represent the characteristics of both, keeping in mind the fact that the present species is more than twice the size of *C. multibrachiatus*, and the corrugations of the surface, in common with other features, are much coarser.

HORIZON AND LOCALITY: Lower Burlington, Burlington, Iowa. No. 552, Museum of Comparative Zoölogy collection.

Cactocrinus limabrachiatus (Hall)

Plate V, figs. 3, 4, 4a, 4b

1861. *Actinocrinus limabrachiatus* Hall, Description of New Species of Crinoidea, Preliminary notice, p. 2.

1897. *Cactocrinus limabrachiatus* Wachsmuth and Springer, North American Crinoidea Camerata, p. 608, pl. 58, figs. 9, 10a, 10b.

The arrangement of plates in the calyx of this species is the same as that already described for species having six arms to the ray. The surface is highly ornamented with strong nodes and carinae, which, on the larger calyces, are of two series. The carinae leading to the arms are much stronger than the others.

The arms of each ray are grouped together, suggesting the arrangement in *Actinocrinus*, although the spaces between the rays are still narrow. The arms are long and slender, cylindrical at the base, but they soon become flattened dorso-ventrally. They are slightly expanded at a distance of about half their length from the base and taper very gradually to the tips. The biserial condition is reached late in the development of the arm, there being from four to seven plates at the base which pass entirely across its diameter. At a distance of from 5 to 8 millimeters from the base, varying on different arms, each plate is ornamented by a projecting transverse ridge near its upper margin, and the surface is covered by strong vertical corrugations. This type of ornament persists to the tip of the arm, while its form changes from cylindrical at the base to strongly flattened above, as shown by the transverse sections, Plate V, figs. 4, 4a, 4b.

HORIZON AND LOCALITY: Lower Burlington, Burlington, Iowa. No. 528, Museum of Comparative Zoölogy collection.

COMPARISON OF THE PRECEDING THREE SPECIES

A comparison of *Cactocrinus multibrachiatus* and *C. cælatus* var. *spinotentaculus* shows the relationship between the two to be so close that they might be considered the same species, were it not that in a large series of specimens, *C. multibrachiatus* shows all the characters of an adult individual, while it is only about half the size of *C. cælatus* var. *spinotentaculus*. The proportionally much higher calyx of the latter is also a distinctive feature. The arms of the two species pass through the same structural changes, which are interpreted as stages of development and are closely similar, except that in *C. cælatus* var. *spinotentaculus*, they are biserial nearer the base and are larger.

It seems reasonable to assume ~~that~~ *C. cœlatus* var. *spinotentaculus* is a direct descendant from *C. multibrachiatus*, differing but little from the latter, its immediate ancestor. I have not seen the arms of *Cactocrinus cœlatus*; hence comparisons are made with its variety, of which well-preserved material is available.

Cactocrinus limabrachiatus resembles *C. multibrachiatus* in the form of the calyx and in the changes in form through which the arms pass. The ornament on the surface of the calyx and the arms of the former species is similar in kind to that of the latter, but is more extreme, the costæ being stronger and more numerous and the corrugations of the arms coarser. In this respect, it is more highly differentiated than *C. multibrachiatus*, but in the number of arms and in the late attainment of the biserial condition it is more primitive. My interpretation of these facts would be that both are descended from a common ancestor but represent divergent lines of evolution, *Cactocrinus limabrachiatus* having developed in the direction of a high degree of surface ornament, while *C. multibrachiatus* has advanced in number of arms and earlier development of biserial plates.

RELATION OF CACTOCRINUS TO TELEIOCRINUS

The derivation of the genus *Teleiocrinus* from *Cactocrinus* has already been suggested by Wachsmuth and Springer,⁸ and it is interesting to note that the development of the arms confirms the evidence derived from the calyx and the mode of branching of the arms.

In *Teleiocrinus umbrosus* (Hall), the type of the genus, the arms are more numerous and more slender than those of *Cactocrinus cœlatus* var. *spinotentaculus*. Their slenderness is perhaps due to their greater number, both on account of economy of material and the crowding due to frequent branching near the base. The method of branching in *Teleiocrinus* follows the *Cactocrinus* plan, each axillary being succeeded by another without intervening plates of the same order until there are fifteen or sixteen arms to the ray. In form, the arms are cylindrical at the base, or in accelerated individuals somewhat flattened even at this point. Higher up on the arms, they become strongly flattened dorso-ventrally and develop a narrow transverse ridge near their upper margins. The corrugations on the surface of the arms are much finer than those of *Cactocrinus cœlatus* var. *spinotentaculus*, as might be expected from the more delicate structure of the whole arm. The arm of *Teleiocrinus umbrosus* is figured on Plate V, figs. 5, 5a. A comparison of these figures with those of

⁸ WACHSMUTH and SPRINGER: North American Crinolidea Camerata, p. 627. Cambridge, 1897.

Cactocrinus cœlatus var. *spinotentaculus* on the same plate shows the close similarity between the arms of the two species throughout their entire development. *Teleiocrinus umbrosus* seems to have been developed from *Cactocrinus cœlatus* var. *spinotentaculus* by an increase in the size and thickness of the calyx plates and a more frequent branching of the arms near their base, which produced the expanded rim of the calyx characteristic of *Teleiocrinus*.

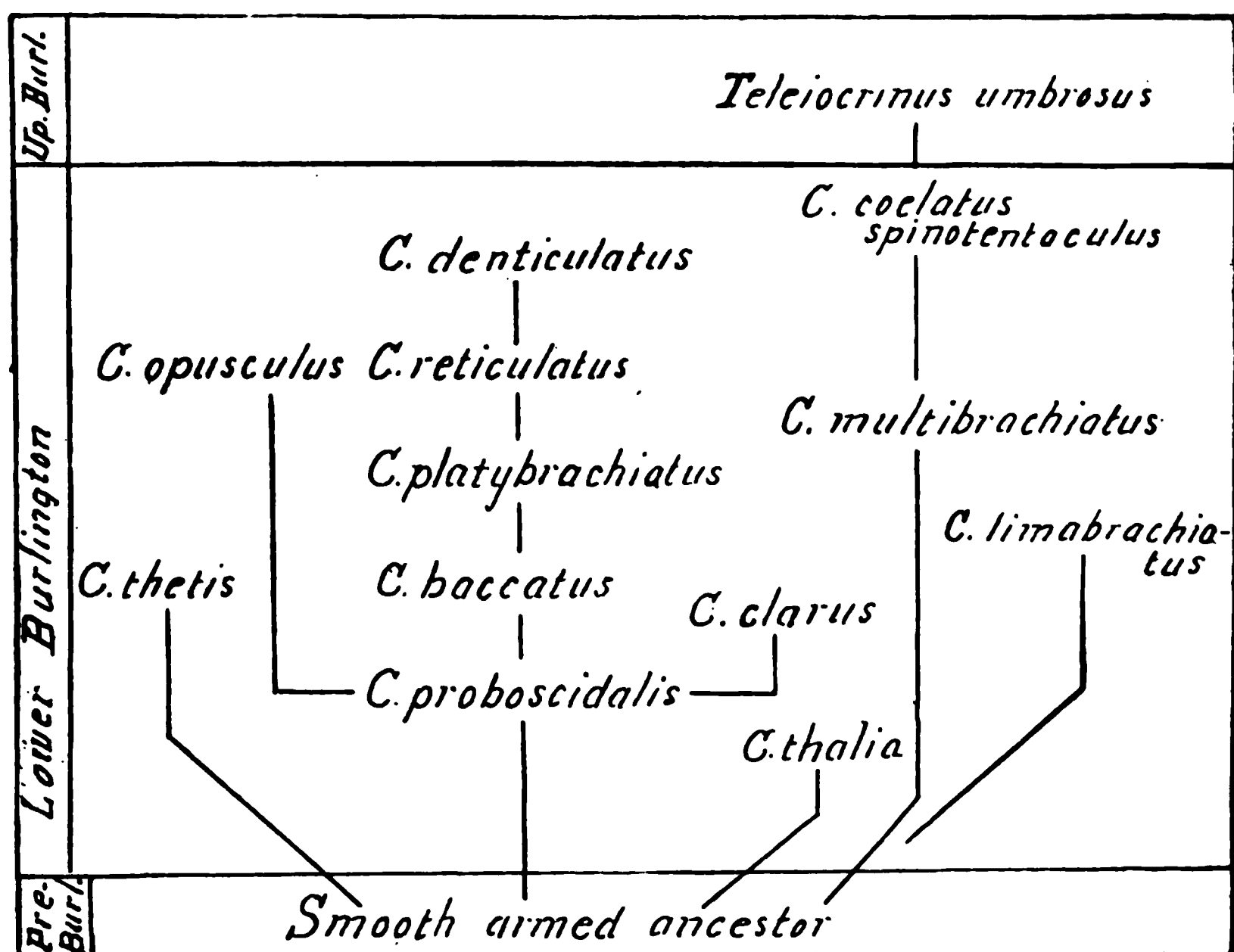


FIG. 1. — Relationship of species of *Cactocrinus* and *Teleiocrinus*

Teleiocrinus althæa (Hall) is represented in the collection of the Museum of Comparative Zoölogy by only one specimen which preserves the arms. From this, it appears that the numerous arms are flattened dorso-ventrally at the base but become larger and cylindrical in form above. This suggests that we have in *Teleiocrinus althæa* an actual advance in evolution expressed in a simplification of form rather than in greater complexity.

The general relations of the species mentioned above are expressed in diagrammatic form in Fig. 1.

CONCLUSION

The considerations presented in the above paper constitute only a beginning in a line of investigation which seems to promise good results, if followed out in genera which have highly modified arms. From the proximal to the distal portion of the arm, we find a series of changes in structural features which succeed one another in a definite order. These changes may be interpreted as stages in development, each individual repeating the stages present in its immediate ancestor and adding, in the distal portion, new characters of its own until the number of characters becomes too great for representation in the life history of a single organism, and certain characters, usually the earlier ones, are greatly abbreviated or are omitted from the ontogeny of highly modified descendants. When thus interpreted, the arms of crinoids furnish evidence from which the phylogenetic relations of different species and genera can be inferred. With the attention once drawn to the subject, it will probably be found that the number of genera which may be studied by this method and the degree of modification existing are greater than would appear at first thought.

PLATE I

FIG. 1.—*Cactocrinus proboscidalis* (Hall). Natural size.

FIG. 2.—*C. platybrachiatus*. $\times \frac{12}{13}$.

FIG. 3.—*C. baccatus* sp. nov. Natural size.

FIG. 4.—*C. opusculus* (Hall). Natural size.

From photographs of the specimens.

1

2

3

4

FROM PHOTOGRAPHS BY W. E. ROWE

HELIOTYPE CO., BOSTON

PLATE II

FIG. 1.—*Cactocrinus proboscidealis* (Hall), dorsal view of arm plates 1 to 8, 50, 70 and 94. Below plate 1, 5 plates of the radial series are included in the calyx.

FIG. 2.—Outline of section of an arm of the same species at plate 50.

FIGS. 2a, 2b.—Similar outlines at plates 70 and 94.

FIGS. 1 and 2, 2a, 2b, were drawn from the specimen figured on Plate I, fig. 1.

FIG. 3.—*Cactocrinus baccatus*, new species, dorsal view of arm plates 1 to 4, 14 to 15, 48 and 67. Below plate 1, 5 plates of the radial series are included in the calyx.

FIG. 4.—Outline of section of an arm of the same species at plate 7.

FIGS. 4a, 4b.—Similar outlines at plates 48 and 73.

NOTE.—The shaded figures on Plates II to V have been drawn by the author from a single specimen of each species, and so far as possible from a single arm. When no one arm was sufficiently complete to show all stages, adjacent arms were chosen. The sections were, in some cases, drawn from a different specimen from that giving the dorsal view of the arm, but the plates chosen for sections show the same structural feature as those bearing the corresponding number in the dorsal view. All figures are $\times 6$.

PLATE II

Fig. 1.—*Cactocrinus proboscidealis* (Hall), dorsal view of arm plates 1 to 3, 50, 70 and 84. Below plate 1, 5 plates of the radial series are included in the calyx.

Fig. 2.—Outline of section of an arm of the same species at plate 50.

Figs. 2a, 2b.—Similar outlines at plates 70 and 84.

Figs. 1 and 2, 2a, 2b. were drawn from the specimen figured on Plate I, fig. 1.

Fig. 3.—*Cactocrinus baccatus*, new species, dorsal view of arm plates 1 to 4, 14 to 15, 48 and 65. Below plate 1, 5 plates of the radial series are included in the calyx.

Fig. 4.—Outline of section of an arm of the same species at plate 5.

Figs. 4a, 4b.—Similar outlines at plates 48 and 73.

NOTE.—The shaded figures on Plates II to V have been drawn by the author from a single specimen of each species, and so far as possible from a single arm. When no one arm was sufficiently complete to show all stages, adjacent arms were chosen. The sections were, in some cases, drawn from a different specimen from that giving the dorsal view of the arm, but the plates chosen for sections show the same structural features as those bearing the corresponding number in the dorsal view. All figures are $\times 6$.

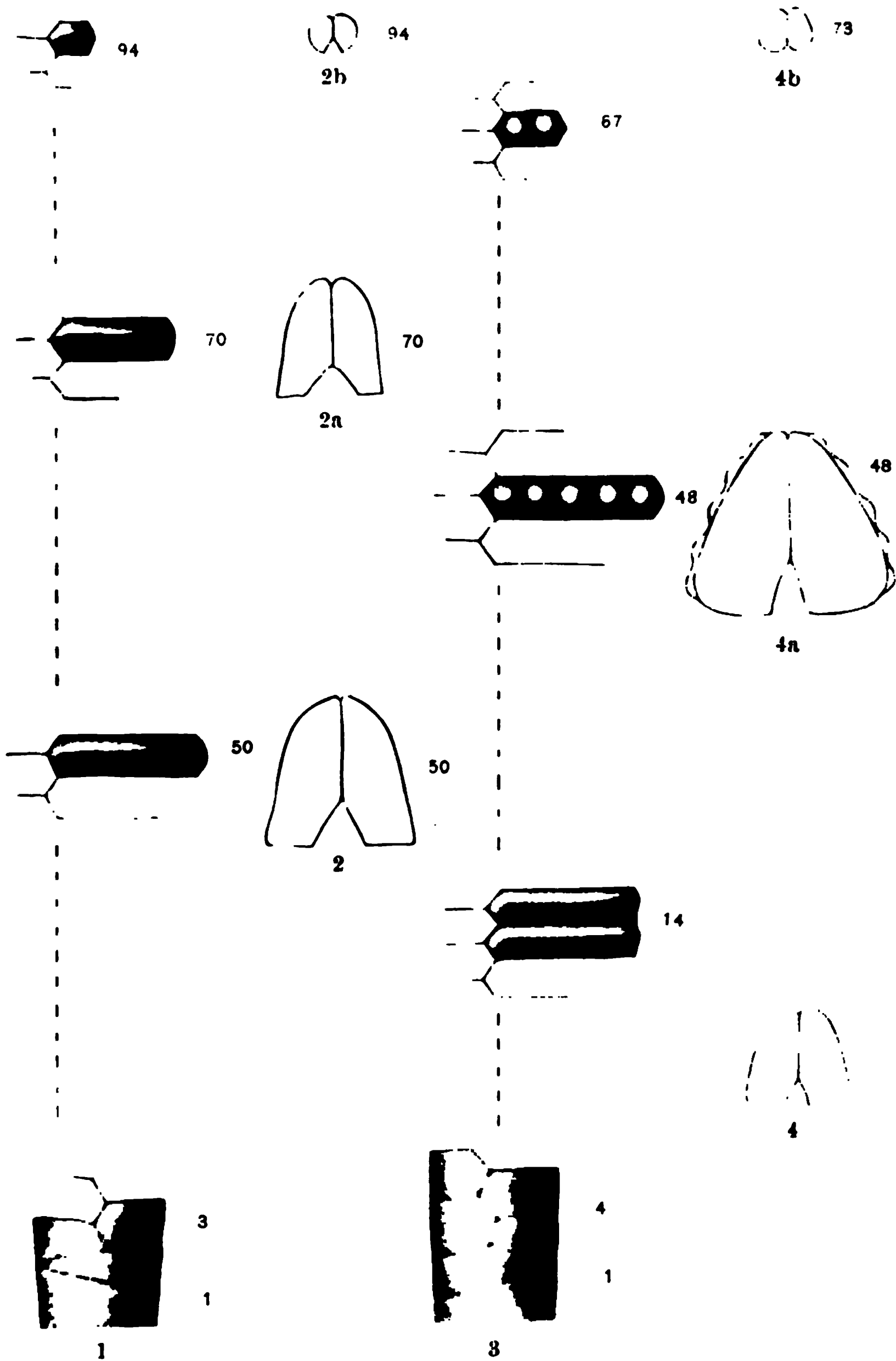


PLATE III

FIG. 1.—*Cactocrinus platybrachiatus*, new species, dorsal view of arm plates 1 to 4, 12 to 13, 26 to 27, 62 to 63, 84 to 85 and 89. Below plate 1, 6 plates of the radial series are included in the calyx.

FIG. 2.—Outline of section of an arm of the same specimen at plate 10.

FIGS. 2a, 2b.—Similar outlines at plates 62 and 84.

FIGS. 1 and 2, 2a, 2b, were drawn from the specimen figured on plate I, fig. 2.

FIG. 3.—*Cactocrinus reticulatus* (Hall), dorsal view of arm plates 1 to 3, about 15, about 30 to 31, 41 to 45, 55 to 56, 82, 96 and 97. The arm figured was imperfect at the base, and the numbers of plates 15 and 30 were estimated by comparison with adjacent arms. Below plate 1, 5 plates of the radial series are included in the calyx.

FIG. 4.—Outline of section of same arm at about plate 30.

FIGS. 4a, 4b, 4c.—Similar outlines at plates 65, 82, and 96.

PLATE III

Fig. 1.—*Curtaria polybrachia*, new species, dorsal view of arm plates 1 to 4, 12 to 13, 26 to 27, 62 to 63, 84 to 85 and 88. Below plate 1, 6 plates of the radial series are included in the calyx.

Fig. 2.—Outline of section of an arm of the same specimen as plate 10.

Figs. 2a, 2b.—Similar outlines at plates 62 and 84.

Figs. 1 and 2, 2a, 2b, were drawn from the specimen figured on plate I, fig. 2.

Fig. 3.—*Curtaria reticulata* (Hall), dorsal view of arm plates 1 to 3, about 15, about 30 to 31, 41 to 45, 55 to 56, 82, 88 and 87. The arm figured was imperfect at the base, and the numbers of plates 15 and 30 were estimated by comparison with adjacent arms. Below plate 1, 5 plates of the radial series are included in the calyx.

Fig. 4.—Outline of section of same arm as about plate 30.

Figs. 4a, 4b, 4c.—Similar outlines at plates 65, 82, and 88.

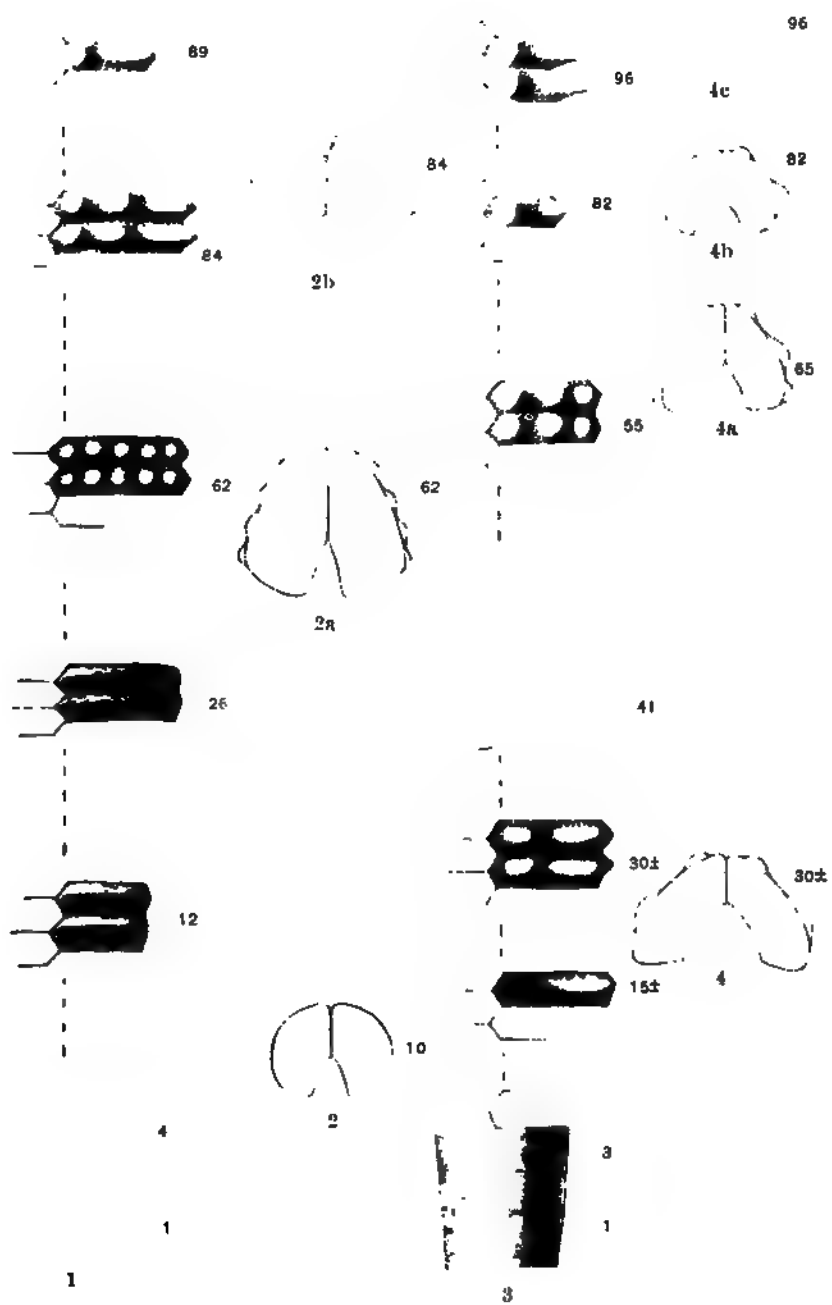


PLATE IV

FIG. 1.—*Cactocrinus denticulatus* Wachsmuth and Springer, dorsal view of arm plates 1 to 4, 8, 34, 48, 56 to 57 and 79 to 82.

FIG. 1a.—Side view of arm plates 2 and 3. The calyx contains 5 plates of the radial series below plate 1.

FIG. 2.—Outline of section of an arm of the same species at plate 34.

FIGS. 2a, 2b.—Similar outlines at plates 56 and 79.

FIG. 3.—*Cactocrinus opusculus* (Hall), dorsal view of arm plates 1 to 3, 10, 30, 40, 52, 75 and 102 to 105. Below plate 1, 6 plates of the radial series are included in the calyx.

FIG. 4.—Outline of section of an arm of the same specimen at plate 10.

FIGS. 4a, 4b, 4c, 4d.—Similar outlines at plates 30, 52, 75, and 102.

FIGS. 3 and 4, 4a to 4d, were drawn from the specimen figured on plate I, fig. 4.

PLATE IV

Fig. 1.—*Conostoma obscurum* (Hall), dorsal view of arm plates 1 to 4, 21, 24, 26 to 27 and 29 to 32.

Fig. 2a.—Side view of arm plates 2 and 3. The calyx contains 5 plates of the radial series below plate 1.

Fig. 2b.—Outline of section of an arm of the same species at plate 34.

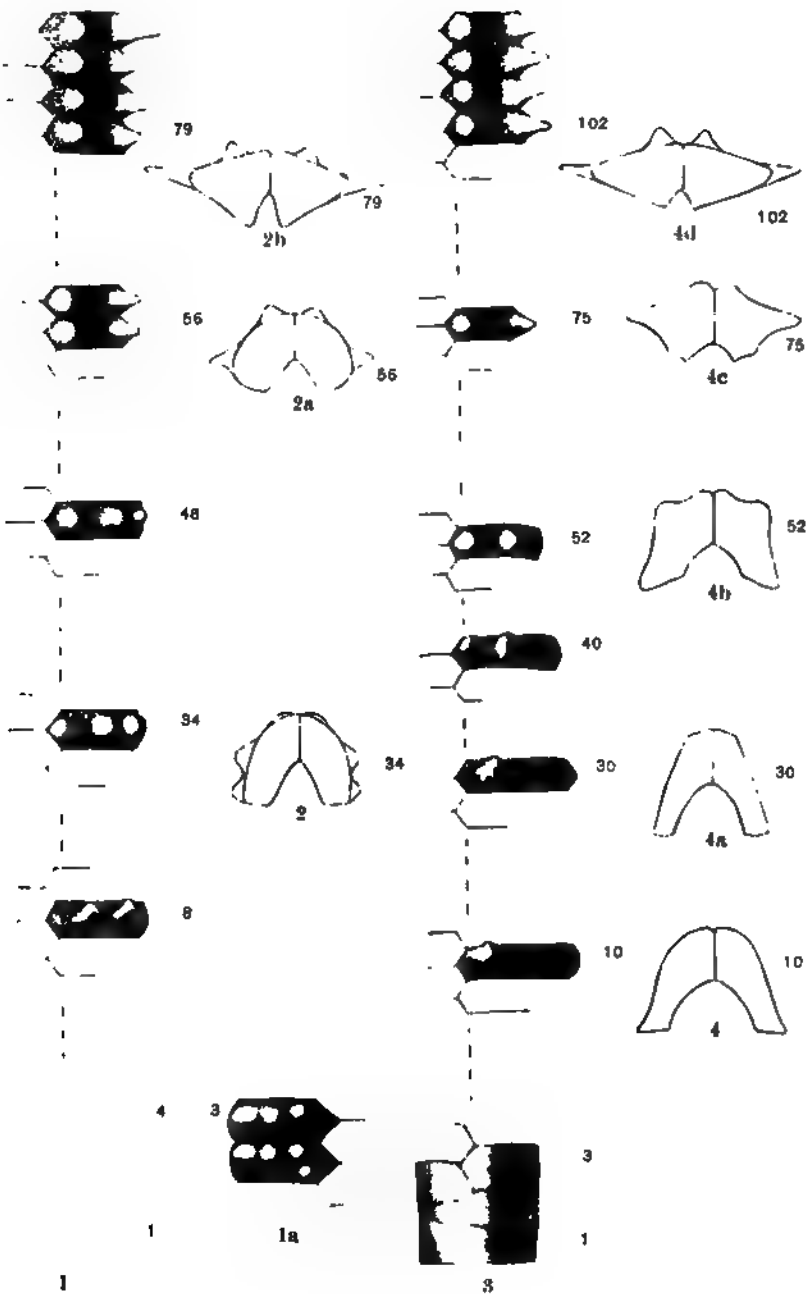
Figs. 2c, 2d.—Similar outlines at plates 56 and 70.

Fig. 3.—*Conostoma obscurum* (Hall), dorsal view of arm plates 1 to 3, 10, 30, 40, 52, 75 and 102 to 105. Below plate 1, 8 plates of the radial series are included in the calyx.

Fig. 4.—Outline of section of an arm of the same specimen at plate 10.

Figs. 4a, 4b, 4c, 4d.—Similar outlines at plates 30, 52, 75, and 102.

Figs. 3 and 4, 4a to 4d, were drawn from one specimen figured on plate I. fig. 4.



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PLATE V

FIG. 1.—*Cactocrinus cœlatus* var. *spinotentaculus* (Hall), dorsal view of arm plates 1 to 2, 70 to 71, 110 to 111. The calyx contains 6 plates of the radial series below plate 1.

FIGS. 2, 2a.—Outlines of sections of arm of same specimen at plates 70 and 110.

FIG. 3.—*Cactocrinus limabrachiatus* (Hall), dorsal view of arm plates 1 to 5, 23 to 24, 50 to 51, 72 to 73, 98 to 99. Five plates of the radial series are included in the calyx below plate 1.

FIG. 4.—Outline of section of arm of same species at plate 23.

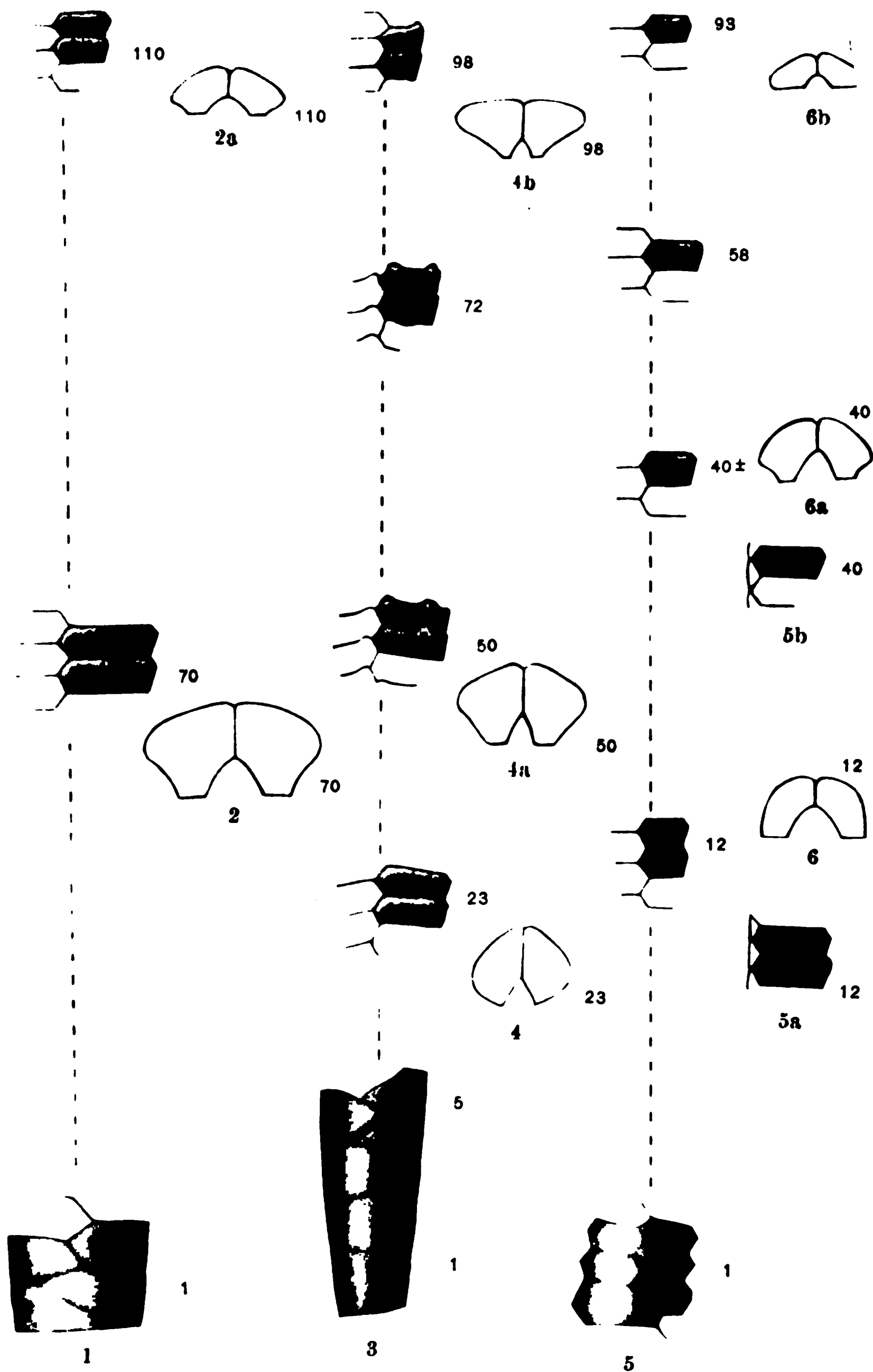
FIGS. 4a, 4b.—Similar outlines at plates 50 and 98.

FIG. 5.—*Teleocrinus umbrosus* Hall, dorsal view of upper plates of calyx and arm plates 1 to 2, 12 to 13, about plates 40, 58 and 93. Below plate 1, 10 plates of the radial series are included in the calyx.

FIGS. 5a, 5b.—Side view of plates 12, 13, and 40 of the same arm.

FIG. 6.—Outline of section of arm of the same specimen at plate 12.

FIGS. 6a, 6b.—Similar outlines at plates 40 and 93.



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PLATE 7

Fig. 1. - *Chelodactylus (Hill)*, dorsal view of arm plates 1 to 2, 70 to 71, 110 to 111. The calyx contains 6 plates of the radial series below plate 1.

Fig. 2. - Outlines of sections of arm of same specimen at plates 70 and 110.

Fig. 3. - *Chelodactylus (Hill)*, dorsal view of arm plates 1 to 2, 22 to 24, 50 to 51, 72 to 73, 92 to 93. Five plates of the radial series are included in the calyx below plate 1.

Fig. 4. - Outline of section of arm of same species at plate 22.

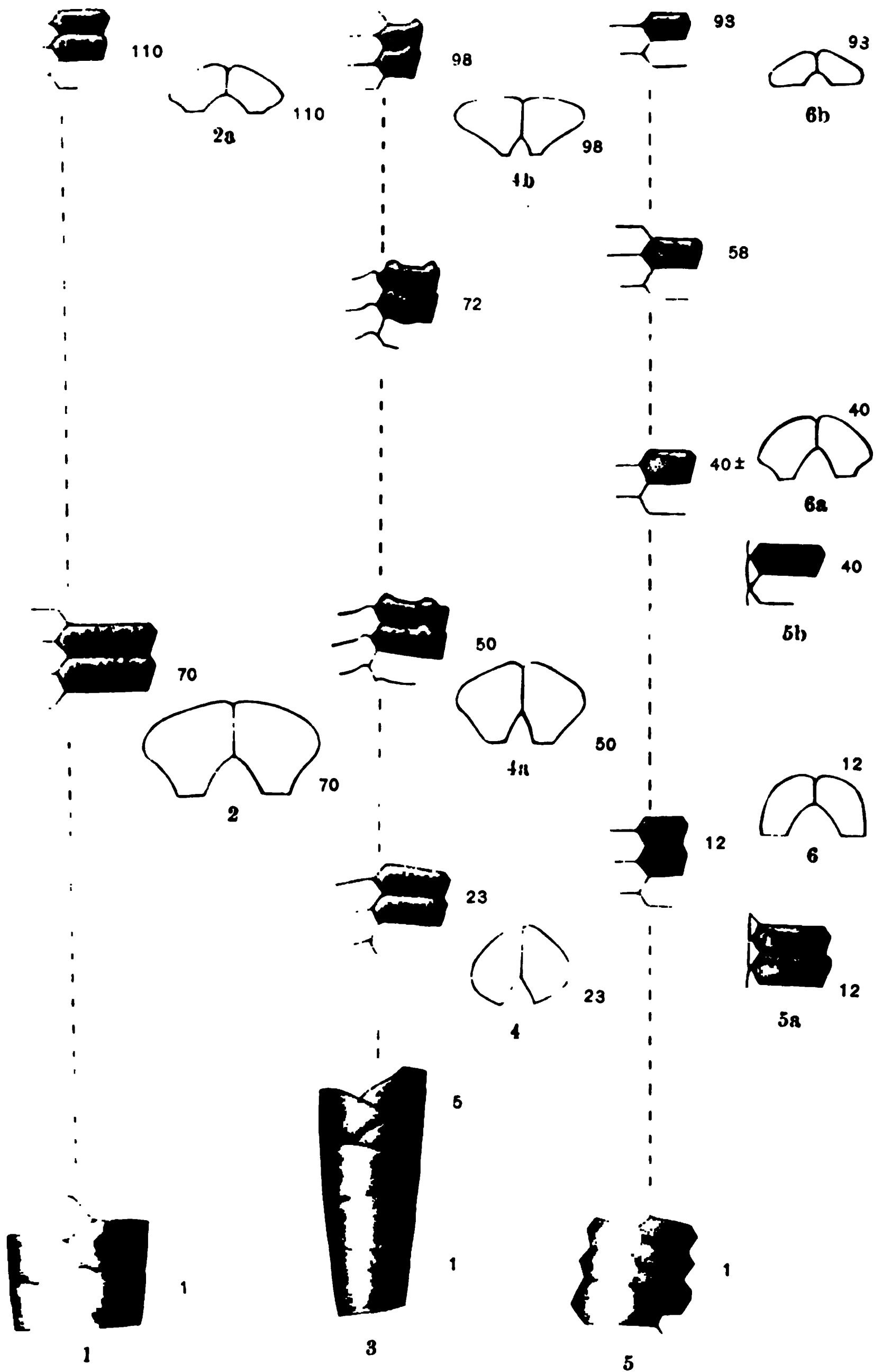
Fig. 4a. - Similar outlines at plates 20 and 32.

Fig. 5. - *Chelodactylus (Hill)*, dorsal view of upper plates of calyx and arm plates 1 to 2, 12 to 13, about plates 40, 72 and 93. Below plate 1, 10 plates of the radial series are included in the calyx.

Fig. 5a. - Side view of plates 12, 13, and 40 of the same arm.

Fig. 6. - Outline of section of arm of the same specimen at plate 12.

Fig. 6a. - Similar outlines at plates 40 and 62.



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NOTES ON CAMARASAURUS COPE

By C. C. Mook

(Read before the Academy, 9 March, 1914)

CONTENTS

	Page
Original description	19
Relationships	21
Cope's restoration	22

ORIGINAL DESCRIPTION

Camarasaurus was originally described by Edward D. Cope in "Paleontological Bulletin 25," published August 23, 1877. The type species is *Camarasaurus supremus*, and the type specimen consists of a cervical, three dorsal and four caudal vertebræ. These bones were found near Canyon City, Colorado, and in the same quarry a considerable number of bones were excavated, belonging to three or more individuals. These bones were more or less associated with the type and it is impossible to say which belongs to one individual and which to another. The vertebræ of the original type may not all belong to the same individual. The various remains are of the same general character and there need be no hesitation in referring them to the same genus and species. Some of these later bones were described in a subsequent paper in the *American Naturalist* for February, 1878, and figures of vertebræ, scapula and pubis were given. All of these remains together now constitute numbers 5760, 5760', 5761, 5761', 5761", 5761a, of the collections of the American Museum of Natural History.

The original description by Cope confounds to some extent the generic characters of *Camarasaurus* with the characters of the Sauropoda as a whole. The hollow centra, and lightly built, laminated neural arches and spines are possessed by all the Sauropoda, some members of the group possessing the lightening structures to a much greater degree than does *Camarasaurus*.

The general characters of *Camarasaurus*, without giving detailed descriptions, are as follows:

Cervicals: Number probably thirteen, of moderate length, of considerable height, with spines double, without a median tubercle.

Dorsals: In the restoration made by Cope the number of dorsals was placed at twenty. Later the series was studied at the American Museum, and a composite column was made up by placing together vertebræ showing progressive fore-and-aft characters. At this time the number was estimated to be fourteen, of which thirteen were actually represented, dorsal two being absent. In the fall of 1913, opportunity was given the present writer by Professor Henry Fairfield Osborn to restudy these vertebræ in preparation for his monograph on the Sauropoda. It was then found that by the elimination of duplicate bones the number is probably ten.

RELATIONSHIPS

The close similarity of *Camarasaurus* with *Morosaurus* has long been considered ground for placing the two genera in the same family. At the present time, it appears that this similarity is close enough to force the conclusion that the two animals belong to the same genus. Among the characters common to *Camarasaurus* and *Morosaurus*, the following may be mentioned:

1. Centra of dorsals increasing gradually in opisthocœlianism from the posterior to the anterior region.
2. Principal laminæ supporting the transverse processes strong, with little development of accessory laminæ.
3. Spines low and broad, with only one cavity of any importance on their sides.
4. Caudals short, with inferior surfaces of centra convex in transverse direction.
5. Scapulæ short, greatly expanded at both proximal and distal ends.
6. Humerus short and stout, index of maximum length into minimum circumference about .440.
7. Ulna slightly twisted at the distal end.
8. Femur very stout, index about .440. Ratio of length of femur to length of humerus about .600.
9. Metacarpals long and slender.
10. Sacral spines low and broad.
11. Ischium slender, tapering distally.

The only characters in which the two forms differ are those which may be taken as individual variations or specific characters, such as size, position of capitular rib facets on anterior dorsals, presence or absence of a median tubercle between the two spines of the anterior vertebræ, or slight differences in the laminar supports of the transverse processes.

It is concluded, therefore, that *Camarasaurus* and *Morosaurus* are generically identical, and as *Camarasaurus* has a priority of about one month, the species now under *Morosaurus* should be referred to the former genus.

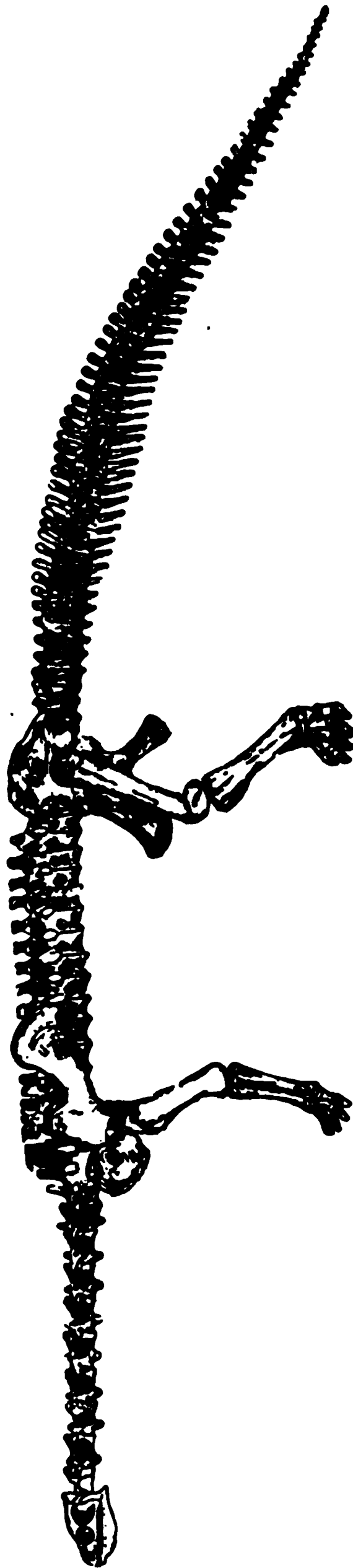


FIGURE 1.—Restoration of *Camarasaurus* by Cope. About 1/100 natural size
The position of the fore limb in relation to the vertebral column was not indicated by Cope

COPE'S RESTORATION

A life-size restoration of *Camarasaurus* was made by Dr. John A. Ryder under the direction of Professor Cope about 1878, parts of several individuals being assembled to make a composite individual.

The material on which the restoration of the skull was based was very incomplete, only the posterior portion of the cranium and the anterior portion of the mandibles being represented. The restoration of the skull was, therefore, almost entirely hypothetical. The teeth were restored as of carnivorous rather than herbivorous type, and were placed along the sides of the jaws instead of in the front as is now known to be the case in the Sauropoda. The teeth extend posteriorly behind the orbit, some of them even appearing to be rooted in the jugal bone.

The cervical and dorsal vertebræ are not distinctly separated in the restoration, nor are the dorsal and sacral. No ribs are represented. The cervical series as restored contains ten or twelve vertebræ, no atlas being represented. The dorsal series contains sixteen, seventeen or nineteen vertebræ, according to the interpretation of vertebræ eleven and twelve as dorsals or cervicals, and vertebra twenty-nine as dorsal or sacral. Sixty caudals are present in the restoration. According to our present knowledge of *Camarasaurus*, the number of cervicals should be twelve or thirteen, the number of dorsals ten, of sacrals five, while the number of caudals is doubtful. In the restoration, there are too many anterior caudals and too few small distal ones.

The bones of the fore-limb are too long in the restoration. Four hypothetical carpal bones are represented. The phalangeal formula of the restoration is 4, 5, 5, 5, 5. The ischium is represented as slightly expanded at the distal end as in *Brontosaurus*, instead of tapering slightly as it does in the type. The tibia and fibula are each about seven inches longer than the actual bones. Three tarsal bones, of which at least one is hypothetical, are represented. The phalangeal formula as restored is 2, 3, 3, 5, 4.

It is interesting to observe that, at this early date, Professor Cope concluded that the Sauropoda walked upright, instead of crawling, as was contended a few years ago by Tornier and others, and denied by Matthew and Holland.

THE GENESIS OF ANTIGORITE AND TALC

BY ALEXIS A. JULIEN

(Presented by title before the Academy, 7 April, 1914)

CONTENTS

	Page
Introduction.....	23
The genesis of talc.....	25
The genesis of antigorite.....	26
Formation of antigorite from olivine by hydration.....	26
Formation of antigorite directly from olivine by thermal alteration...	28
Direct hydration by agencies between two belts.....	29
Dual processes in genesis of talc and antigorite.....	30
Genesis of chrysotile and retinalite.....	33
Composite veins.....	36
Conclusions.....	38

INTRODUCTION

The avowal of Delesse in 1865—"Above all other eruptive rocks, serpentine has hitherto remained a veritable enigma!"—still pertains to all prevalent hypotheses concerning its origin. Although indeed the existence of a "serpentine group," as complex as Schweizer's series (picrosmine, picrophyll, substance *e*, antigorite, serpentine, chrysotile and other substances *a*, *b*, *c*, *d*, *f*) is no longer in common acceptance, there are few mineralogical authorities even now who are not inclined to favor at least the dual distinction, "serpentine" and chrysotile, with differentiation as allomorphs in physical and optical characteristics if not in chemical composition. The solution appears to have been long delayed by ignorance of certain facts:

1). *The impurity of specimens.*—The term "serpentine" has been indifferently applied to all forms of the mineral, and, with the same freedom, to the massive rock, often designated as "ordinary serpentine," in which the proportion of the mineral rarely exceeds 60 to 80 per cent. and may even fall to 35 per cent. or less. In opposition to this loose practice, Lacroix has long ago urged the restriction of the term "antigorite" to all forms of the mineral proper, and of the term "serpentine" exclusively to the rock occurrences. Analogy with the precision obtained by discrimination of calcite from limestone, of dolomite (or miemite, ac-

according to some) from magnesian limestone, of talc from steatite, etc., confirms the advantage of such distinctive use of the two terms, if antigorite as a definite mineral shall be held to comprise all substances of the composition $H_4Mg_3Si_2O_{10}$.

In most of its specimens, however careful their selection for apparent purity, as judged by uniform texture, color and translucency, such as "noble serpentine," retinalite, etc., the evidences of large intermixture with other substances are readily established. As this impurity mainly consists of other magnesian salts, the usual method of identification of antigorite by deduction of certain molecular ratios from the analysis is by far too rude and unreliable. Only by recasting of the analysis,¹ with precise reference to the percentage of combined water and, if possible, with control by microscopic and optical examination of the very material used for the analysis, can the true constitution be determined for the aggregate present in almost every specimen of the presumably pure mineral. An unfortunate consequence of disregard of these precautions has been the partial vitiation of many physical and chemical investigations of the mineral. For example, it is easily determined, by recasting of the stated analyses, that specimens of the "dark green serpentine" from Newburyport, Massachusetts, selected as typical in experiments for determination of constitutional formula,² actually contained 11 to 22 per cent. of deweylite, etc.; and that the foliated antigorite from Antigorio, Piedmont, used for determination of the form of silicic hydrate existing in the constitution of true antigorite,³ contained 15 per cent. of prochlorite, deweylite, etc. It may be fairly suspected that this impurity of material may have led in part to uncertainty attending conceptions of that constitution.

In regard to talc, its ordinary intermixture with quartz, chlorite, antigorite, tremolite, etc., is well known.

2). *The obscurity of the products of decay in laterite.*—In past discussions, the grains of antigorite and scales of shining talc detected on weathered outcrops, though merely ancient elements residual from their insolubility, have been commonly mistaken for new generations. This misleading presumption has hindered recognition of the actual abundant derivatives from rock decay, magnesia, its hydrate, carbonates and soluble hydrosilicates. The resulting discordance of inferences from the numerous proposed genetic hypotheses for talc and antigorite, with facts even

¹ Ann. N. Y. Acad. Sci., XVIII, 129-146. 1908.

² CLARKE AND SCHNEIDER: Am. Jour. Sci. (3), XI, 308. 1890.

³ S. HILLEBRAND: Sitz.-ber. d. math.-naturw. Kl. d. r. Acad. d. Wiss., Berlin, CXV, Abt. I, 697-712. 1906.

then known concerning the products of weathering of ferro-magnesian minerals and rocks, may be briefly reviewed in connection with each mineral.

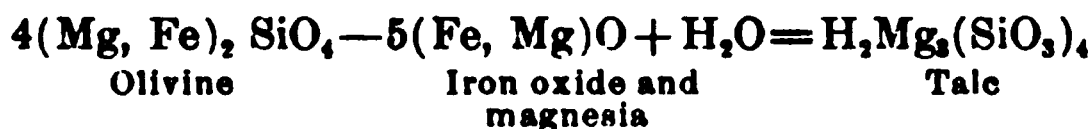
THE GENESIS OF TALC

In regard to talc, T. S. Hunt⁴ in 1860 made the following suggestion, without further elaboration:

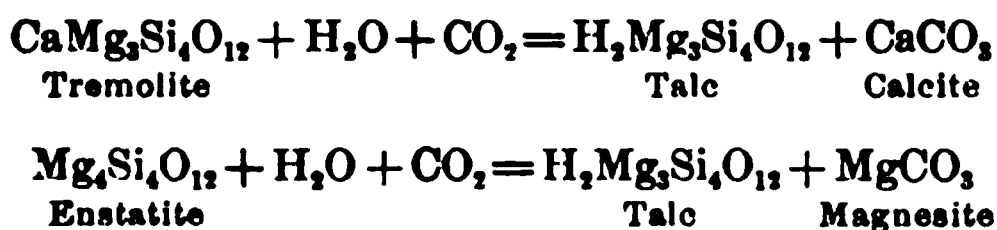
"While steatite has been derived from a compound like sepiolite, the source of serpentine was to be sought in another silicate richer in magnesia."

In this, his conjecture concerning talc was a happy one and was approved by Delesse in 1861. By neither was there ever advanced any explanation or proof and the fleeting suggestion dropped from view.

Taking for example a single mineral, olivine, as the source of talc, as in the peridosteatites of Maryland and North Carolina, the following genetic equation, for direct alteration of olivine into talc, has been proposed :⁵



So also the derivation of talc from tremolite or enstatite has been attributed to attack by carbonated waters, as explained by the reactions⁶



According to another authority:⁷

"Talc forms in the upper zone of metamorphism. In this respect it is like chlorite and serpentine. It is especially likely to form under conditions of weathering. . . . It appears to be one of the end products of rock alteration in the belt of weathering."

Yet in the decay of olivine, for example, on weathered outcrops of dunite or other peridotite, while there can be no doubt of the removal of iron oxide and magnesia and of absorption of water, not a trace of newly formed talc has ever been distinguished among the products of decay. Furthermore, the above equations take no note of the free silica which has universally separated in abundance during development of

*** Chem. and Geol. Essays, Boston, 296. 1875.**

⁵ J. H. PRATT AND J. V. LEWIS: N. C. Geol. Survey, I. 1905.

***C. H. SMYTH, JR.:** Sch. of Mines Quart., XVII, 333. 1896.

¹ C. R. VAN HISE: Treatise on Metamorphism, U. S. Geol. Surv. Monogr. 351. Washington, 1904.

talc and has become either a prominent constituent of the resulting quartz-talc aggregate, steatite, or a prominent associate in veins or seams in close vicinity to a talc-rock.

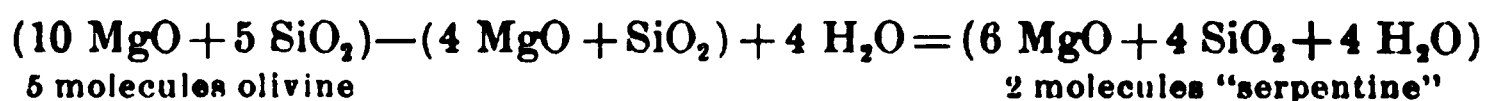
THE GENESIS OF ANTIGORITE

For the purpose of this paper it will be unnecessary to discuss all the hypotheses which have been devised, or to consider but one important source, olivine. A review of the literature reveals, in my opinion, progressive but still imperfect recognition of the nature and conditions of the genesis of antigorite, and, on the other hand, a growing consciousness of the insufficiency of the tentative speculations concerning its location. These comprise three methods of change of olivine directly into antigorite, viz: by weathering, by attack of deep-seated agencies and by combination of both.

FORMATION OF ANTIGORITE DIRECTLY FROM OLIVINE BY HYDRATION

The hydration which antigorite represents toward olivine as the mother-mineral, the visible evidences of its production by attack from the outside upon the olivine grains, the attending oxidation of ferrous iron, the removal of certain bases and the release of free silica are obvious results of the decay by weathering. What conclusion more simple and plausible than that antigorite has been mainly produced in such instances by direct hydration of olivine?

An early writer (J. Roth,⁸ 1869), although he had distinguished various processes of weathering as simple and complex, discussed antigorization under the former heading, thus.



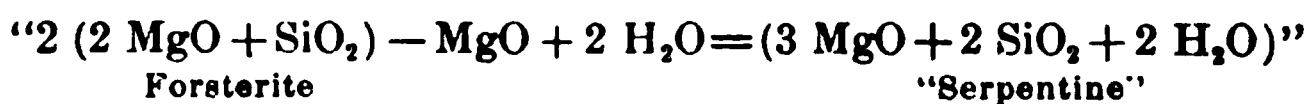
J. J. H. Teal⁹ (1888) was content to declare:

"The alteration of olivine by surface agencies—water, carbonic acid and oxygen—gives rise to serpentines and other pseudomorphs;"

and

"the formation of serpentine by the alteration and hydration of ferro-magnesian and magnesian silicates is proved beyond all question,"

with the equation:



⁸ Abh. d. k. Akad. d. Wiss. Berlin, 1869.

⁹ British Petrography, 104-106. London, 1888.

combined water, shows that his dried residue consisted to 97 per cent. of deweylite, $H_{12}Mg_4Si_3O_{16}$, without any antigorite.

FORMATION OF ANTIGORITE DIRECTLY FROM OLIVINE BY THERMAL ALTERATION

The development of newly formed antigorite among the products of weathering was indeed long ago questioned by Ebelmen and others. T. S. Hunt declared its entire absence from the weathered coat over the peridotites at Montreal, Canada. G. P. Merrill and T. H. Holland also have held that it is never found as a weathering product of olivine, or as a constituent of laterite. Therefore, hypotheses have been devised at the other extreme, according to which the genesis of antigorite directly from olivine has been effected solely in a deep-seated zone of special hydration below the belt of weathering. This may have progressed as "common hydrometamorphism," at a moderate thermal temperature and depth, under the influence of moisture permeating rocks below the ground water level, such waters not favoring oxidation and containing no great amount of carbonic acid. "Being an essentially deep-seated process, serpentization should certainly not be referred to weathering" (W. Lindgren). Its evidences are found in the entire absence of oxidation during the passage of olivine into antigorite (G. P. Merrill, 1899); in the greater production of magnetite than hematite from the iron oxide in ferriferous olivine, thus pointing to the scarcity of atmospheric oxygen during the hydration of that mineral into antigorite (J. H. Pratt and J. V. Lewis, 1905).

Other writers look to a still deeper zone of alteration to account for the high water content of antigorite, as indicating connection with orogenic processes (Rosenbusch, 1901); there are evidences of pressure, particularly in alteration from augite, which has served as a most important factor in the development of antigorite (T. G. Bonney, 1908); with the characteristics of a deep-seated process, due to waters or vapors coming from considerable depths, or even constituents of the magmas at the time of their intrusion, which may be distinguished as hydrometamorphism (G. P. Merrill, 1899); an alteration which may have been the effect of prolonged submergence in sea-water under high pressure (T. H. Holland, 1899).

The variety of peridotite "stubachite" has been attributed to "a post-volcanic, perhaps pneumatolytic process, following a period of pneumato-hydrogenic action,"¹³

¹³ E. WEINSCHENK: N. Jhrb. f. Min., I, 226. 1895.

even though quite free from the mineralizers, etc., characteristic of that process. It consists of a crystalline aggregate of olivine and antigorite—the latter designated as “primary,” i. e., of supposed contemporaneous intergrowth with the olivine.

All the foregoing forms of the hypothesis of limitation of antigorite-genesis to a deep-seated zone are, in my judgment, controverted by internal evidence, the common survival of deweylite in the chemical composition and the common association of chrysotile, each with a genetic history essentially connected with lateritic decay.

Not having yet found any analyses of “stubachite,” we have at least the evidence that it is accompanied by an abundance of chrysotile, together with “schweizerite,” a substance shown by its analyses to consist of a mixture of massive antigorite, chrysotile and nemalite. “Stubachite” therefore appears to pertain to a peridotite (dunite) once partly saturated with deweylite, brucite and sepiolite in the belt of weathering, which have been later converted respectively into crystalline antigorite, chrysotile and talc, at a temperature far less than that attending pneumatolytic action.

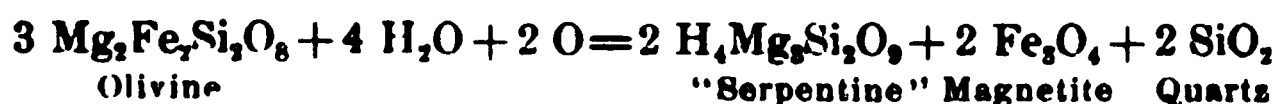
DIRECT HYDRATION BY AGENCIES WITHIN TWO BELTS

On account of the strong alliance, rightly suspected, of the associations and characteristics of antigorite with the processes and products both of the belt of weathering and of a more deep-seated region, other writers would embrace a broader zone as the location for conversion of olivine directly into antigorite. As this has been expressed by Van Hise:¹⁴

“Serpentine is a product of the zone of katamorphism, including both the belt of cementation and the belt of weathering.”

In these hypotheses, the dual character is applied only to the locations and the range of conditions considered requisite for completion of a single process for derivation of antigorite directly from olivine. This is shown by the fact that, in every case, a single equation suffices these authors to explain the supposed reactions. There is a general vagueness concerning the actual process, but no questioning of its essential unity of reaction.

For the above view, based upon the apparent simplicity of direct addition of water and oxygen to produce antigorite, the following reactions, among others, have been suggested by Van Hise:¹⁵



¹⁴ *Op. cit.*, p. 349.

¹⁵ *Op. cit.*, p. 310.

Here, as in most equations which have been suggested in discussions of mineral genesis, the initial colloid condition of most products of mineral decay has been disregarded. Besides this, the minerals assumed apparently as derivative within the belt of weathering—antigorite, magnetite, hematite—are those which have surely taken their birth or acquired crystalline form in a lower and thermal belt of alteration. The difference of view on the common products of olivine decay (omitting double salts) within the belt of weathering may be contrasted as below:

<i>By common hypothesis.</i>	<i>By observation.</i>
Quartz, hyalite, opal	{ Colloid silicic hydrates; amorphous hyalite, chalcedony; quartz.
Pyrolusite	{ Colloid or amorphous manganese hydrate, hydrocarbonates, carbonate and hydrosilicates; pyrolusite.
Genthite, garnierite	{ Colloid or amorphous nickel hydrates, hydrocarbonates and hydrosilicates (connarite).
Siderite, magnetite, hematite	{ Colloid ferric or ferroso-ferric hydrates, hydrocarbonate, carbonate, hydrosilicate, in part amorphous; siderite.
Calcite, dolomite	{ Colloid or amorphous calcium carbonate, hydrocarbonates and hydrosilicates; calcite, dolomite.
Brucite, magnesite, hydromagnesite.	{ Amorphous magnesia; amorphous magnesium hydrate, hydrocarbonates, carbonates; brucite, hydromagnesite, magnesite.
Antigorite, talc, deweylite, sepiolite.	{ Colloid magnesium hydrosilicates (deweylite, sepiolite), in part amorphous.

In the equations above given to illustrate the supposed direct conversion of olivine into antigorite, the calculated volume changes varied from + 12 to + 37 per cent. To this expansion and subsequent shrinkage, the phenomena of fracture, gliding, slickensiding, etc., observed in many bodies of serpentine, have been attributed by G. P. Merrill and others.

DUAL PROCESSES IN GENESIS OF TALC AND ANTIGORITE

The object of the present paper is to distinguish and define my conclusions (without the evidences) concerning the dual processes as well as dual regions of alteration—first, the belt of weathering, and later the lower region, connected with development of both talc and antigorite from olivine.

Three other minerals, hitherto treated merely as interesting accessories during development of talc and “serpentine”—viz., brucite, sepiolite and deweylite—now offer their claim as essential elements, in amorphous or colloid form, to the genesis of the two minerals in question. The key to

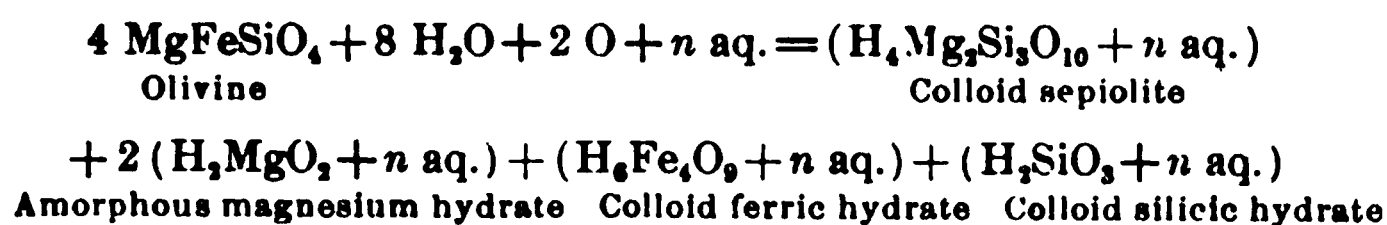
that genesis, I believe, lies in the relationship in each case of a colloid magnesium hydrosilicate (Type I), originating from decay of olivine or other ferro-magnesian mineral, during weathering, to a complementary hydrosilicate (Type II), containing more silica and magnesia and less than about half as much water, into which the former has been afterward converted in a lower region of metamorphism.

The four known magnesium hydrosilicates may be thus arranged to show this relationship of the two types:

Type.	Derivation.	Product.	Formula.	Percentage composition (disregarding n aq.).		
				SiO ₂	MgO	H ₂ O
I.	From decay of olivine.	Sepiolite (colloid).	$H_4Mg_2Si_3O_{10} + n$ aq...	60.80	27.10	12.10
II.	From alteration of sepiolite.	Talc.....	$H_2Mg_3Si_4O_{12}$	62.00	33.10	4.90
I.	From decay of olivine.	Deweylite (colloid).	$H_{12}Mg_4Si_5O_{16} + n$ aq..	40.20	35.70	24.10
II.	From alteration of deweylite.	Antigorite..	$H_4Mg_3Si_2O_9$	43.50	43.52	12.98

The processes involved in the development of these four minerals in nature may be represented in part by the following equations, confining our attention to the single mother-mineral, olivine, out of the twenty-three known to pass into sepiolite and deweylite.

For talc:



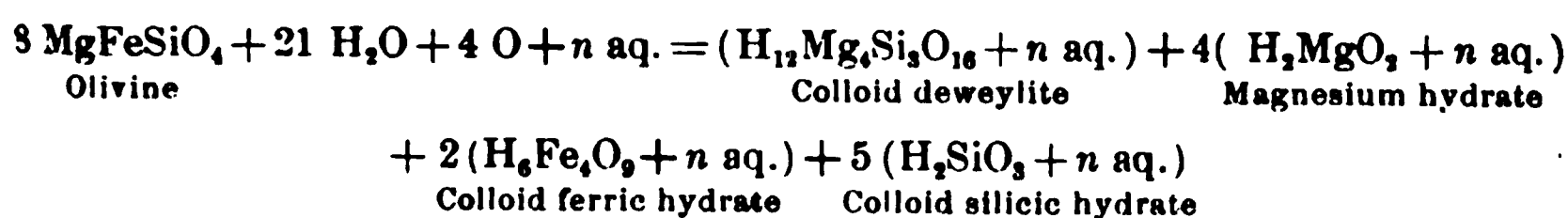
Essential volume change (disregarding n aq.) = + 67.40 per cent.
Then in a lower region:



In massive form the normal rock aggregate, steatite, has thus become developed, a mixture of talc and quartz.

Essential volume change¹⁶ = — 32.96 per cent.

For antigorite:



¹⁶ Without regard to n aq.

Essential volume change¹⁶ = + 80.31 per cent.

It will be noted that incipient development of both sepiolite and deweylite from mineral decay has been attended by separation of a certain amount of magnesium hydrate. This was not understood, except by Roth and Teal, or included in the formulas previously given; it may serve as a test of the truth of the reaction here set forth.

Later, with subjection of deweylite to the thermal conditions in a lower metamorphic belt, the complementary process of alteration has taken place:



Essential volume change¹⁶ = — 32.79 per cent.

Reference has already been made to commonly accepted views concerning dynamic effects upon bodies of serpentine by the changes of volume in progress during passage of minerals into talc and antigorite. It is now apparent that admission into the equations of the hydrated colloids of sepiolite, deweylite, etc., actually found in nature, would involve an early hypothetical expansion far greater than hitherto estimated. On the other hand, the later physical changes which have preceded the birth of talc and of antigorite have generally culminated in notable contraction of the rock mass. We have to do here, however, with more than chemical reactions. The attendant physical processes of solution, leaching, transport and migration of soluble constituents, and their later alteration in a deeper thermal zone, have resulted in a complex fissuring, and often in an amount of contraction which has decidedly offset the expansion from early chemical changes. The observed evidences of internal disruption and movement in bodies of serpentine may be therefore everywhere explained, I judge, by successive throes of expansion and contraction—*e. g.*, at Staten Island and New Rochelle, New York; Montville and Hoboken, New Jersey, and Thetford, Canada—and also by local strains and faults produced by orogenic disturbances.

For precise definition of processes above considered, I think we need differentiation of the following terms:

Decay of rocks, to express the result of operations within the belt of weathering, disintegration, oxidation and extreme hydration. Among the more important products are the colloid magnesium hydrosilicates of the first type (colloid deweylite, sepiolite), magnesium oxide, hydrate and giobertite, besides various forms of ferrous and ferric hydrates, hydrocarbonates, etc.

¹⁶ Without regard to *n* aq.

Alteration, to express the interchanges and consequent new formations, with great loss of water, which take their birth in a more deeply seated region. The common products are the magnesium hydrosilicates of the second type (talc, antigorite), hardened deweylite, forms of limonite, göthite, turgite, hematite, etc.

Decomposition (*Zersetzung* of Roth), to express the molecular dissociation, still more complex interchanges, and still greater to complete dehydration, which have ensued within the zone of anamorphism. Examples of these products are periclase, spathic magnesite, dolomite, siderite, breunerite, regenerated olivine (boltonite, forsterite), specular iron, magnetite, etc.

In regard to the term "hydrometamorphism," whether in the sense of Lindgren, referring to the action of meteoric or vadose waters, or in that of G. P. Merrill, referring to the action of waters from deep-seated sources or from magmas, I find no application for it below the belt of weathering. There only has originated the highest hydration; below it, every change has been attended by progressive loss of water.

GENESIS OF CHRYSOTILE AND RETINALITE

In Plate VI, a well-known laminated variety of asbestos-rock from Thetford, Canada, is presented. Here lie the leaves, silver and green, in long succession, of the book of the history of asbestos, waiting for interpretation of the mystery of its origin.

If "serpentine," as long believed, is a colloid, incapable of crystallization, is this fibrous chrysotile but an alteration product from asbestiform amphibole or bronzite? Or are these fibers only "serpentine" wires, protruded through pores in the vein walls, like those of metal in the arts? Or, along fault planes, has the serpentine been rolled out and sheared into these silky threads? Or, if there be a crystalline paramorph of amorphous "serpentine," is this its fibrous deposit from lateral infiltrations into rock fissures? Is it possible that these have been generated by diamagnetic secretion along the vein walls, expelling into the median fissure of the vein the feebly magnetic brucite, poor in iron, and the diamagnetic calcite? Or are the fibers in fact capillary or acicular crystals either of "serpentine" itself or of its paramorph, thrust from one wall to the other, or grown simultaneously inward from each wall?

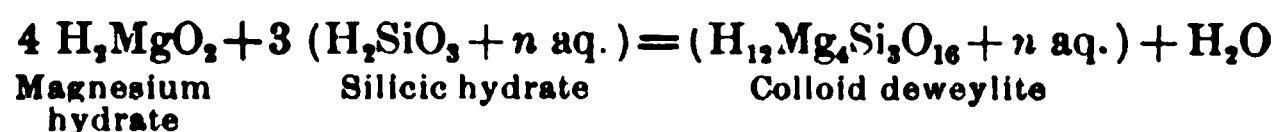
It is doubtful whether any one of these conjectures has proved satisfactory even to its author.

Toward solution of this part of Delesse's enigma, in my turn, it remains to sketch some of the migrations and transformations of the magnesian derivatives from rock decay, as they oozed downward from

laterite into fissures and occupied them as vein deposits. Magnesium hydrate, the most soluble and mobile, was the earliest to form a coating on each wall, sometimes filling up the entire fissure. So originated the veinlets of brucite, crystalline at Hoboken, New Jersey, and crystallized at Hopansuo, Finland, and Texas, Pennsylvania.

The next stage in the process has been connected with the tendency of brucite, when subjected to rock-strains, to molecular rearrangement in direction of the pressure. Its grains become shot through with parallel lines, without regard to the cleavage, and at last transformed into aggregates of fine fibers. Thus brucite has frequently passed into its fibrous allomorph, nemalite, with fibrillation normal to the vein walls, well shown at Hoboken and Montville, New Jersey, Xettes in the Vosges, etc. From solution in carbonated waters, veins of the less soluble carbonates, hydromagnesite, magnesite, etc., have been also produced, or from the action of such waters on brucite already deposited, as at Hoboken, many localities in California, etc.; or where nemalite has occurred, coating each wall of a vein, the interspace remains sometimes filled up with laminated brucite, as at Hoboken, or with magnesite, as at Montville.

Next, by passage of siliceous waters, crystalline brucite has been converted into its antigorite-pseudomorph, marmolite (as shown by Volger and others) at Hoboken and elsewhere, and its crystals into "thermophyllite" at Hopansuo. In the marmolite of Hoboken, pearly flakes of unaltered brucite can be sometimes plainly distinguished. This again implies the intervention of deweylite, and there is abundant evidence of its generation by the following process—reaction of free magnesium oxide, hydrate or carbonate, or of dolomite, with percolating solutions of silicic hydrate or of alkaline silicates. Of the resulting equations it will suffice here to offer the following:



Volume change (disregarding $n \text{ aq.}$) = — 3.75 per cent.

Deweylite of this origin, subjected to thermal conditions, passed into antigorite by the reaction already explained.

Where silicification of nemalite took place, it was converted into deweylite with pseudomorphous fibrillation, and this, by later thermal action, into its antigorite-pseudomorph, chrysotile. The passage of nemalite into chrysotile, supposedly direct, was detected by G. H. O. Volger¹⁶ in specimens from Hoboken in his cabinet, but the intervention of deweylite was not suspected.

¹⁶ Entwicklung der Mineralien der Talk-Glimmer Familie, Zürich, 254–270. 1855.

The office of deweylite has not ever been recognized, doubtless in part on account of the difficulty of detection of a colloidal amorphous substance, and in part of its general alteration into antigorite. Evidence of the latter change is revealed by the frequent partial survival of deweylite grains in intermixture, and also by the very chemical composition of many specimens of antigorite.

For example, T. S. Hunt made among others the following analysis¹⁷ of chrysotile

"from a narrow vein traversing the Eozoon rock of Petite Nation seignory, Quebec: silica, 43.65; magnesia, 41.67; protoxyd of iron, 1.46; water, 13.48; 100.16."

He commented thus, with surprise, on his results:

"these serpentines from the Laurentian limestones are remarkable for their freedom from iron oxide, for their large amount of water, and their low specific gravity."¹⁸

These anomalies are explained by the results of my recasting of his analysis: antigorite, 95.13; deweylite, 4.63; hyalite, 0.40. In development of the pseudomorphs, marmolite from brucite and chrysotile-asbestos from nemalite, a steady progression in contraction is shown, to about one-third of the volume, without disturbance by expansion, from the original magnesium hydrate to the final product, antigorite. This seems to be correlated with the perfect preservation of all structural details, even to the most delicate features of nemalite.

This genetic history of chrysotile, if accepted, enables us to use its occurrence as a test of conditions which have always prevailed during genesis of antigorite from decay. Its general association with the other forms of that mineral, even at the "stupachite" locality, establishes identity of origin through the dual processes already explained.

Colloid deweylite, the magnesian companion of brucite in migration from laterite, has likewise been concentrated in simple veins, as at Texas, Pennsylvania, Bare Hills, Maryland, etc. Where a portion of the deweylite has escaped the subsequent alteration, its intermixture has produced the waxy, translucent variety of antigorite, retinalite, common at many localities. Its analyses invariably reveal an unusually high percentage of combined water, due entirely, as shown by the recasting, to the presence of several per cent. of unaltered deweylite. Moreover, specimens are not uncommonly sprinkled with visible grains of that mineral.

¹⁷ Rpt. Prog. Geol. Surv. Can., 205. Ottawa, 1866.

¹⁸ Am. Jour. Sci. (2), XXVI, 68. 1864.

COMPOSITE VEINS

While the separate deposition of both magnesium hydrate and colloid deweylite has frequently taken place, as described, in simple veins of each mineral, nevertheless their normal and probably more common mode of conveyance from laterite downward has been in intermixture. Composite veins have resulted by separation of successive deposits of each from this mixture, and not, as might first be judged, by a series of deposits upon each wall, now of one mineral, now of the other, in alternation.

A simple form has consisted of a vein with wall coatings of brucite or nemalite, with a middle sheet of deweylite. By silicification, the wall coatings have passed into fibrous deweylite, and this, by later alteration, into chrysotile-asbestos, with a sheet of massive antigorite or retinalite intervening, as at Portchester, New York, etc.

The reverse order of arrangement has been also observed, with sheets of massive antigorite or retinalite (*i. e.*, originally deweylite) coating the walls, and a central sheet of brucite, nemalite and sometimes calcite, as in the Vosges; or with a central sheet of nemalite, in part chrysotile, as at Hoboken.

A proof of the above suggested intermixture of the two magnesian components is yielded from study of analyses of retinalite. A specimen "associated with eozone" at Calumet, Quebec, gave T. S. Hunt the following results: silica, 41.20; magnesia, 43.52; ferrous oxide, 0.80; water, 15.40; 100.92. My recasting of this reveals the following constitution: antigorite, 83.90; deweylite, 11.76; brucite, 5.24. That is to say, a notable portion of each of the original magnesian components has escaped alteration and remains intermixed with the antigorite.

An interesting example of such intermixture has been observed in a symmetrical asbestos vein, two inches in width, in dark green serpentine containing particles of chromite, on lot 13, Range V, Thetford, near Robertson station, Canada.¹⁹ The first deposit on each wall has been a thin layer of dark blue antigorite (originally deweylite) "with grains of chromic iron"; then a layer of chrysotile (originally brucite), with fibration normal to the wall; then a thin layer of pale-green retinalite (originally deweylite); and a central sheet, about $\frac{1}{4}$ inch thick, of dark blue antigorite (originally deweylite mixed with magnesium hydrate), along the middle of which run minute seamy partings of chrysotile (originally brucite) parallel to the plane of the vein.

A succession of four passage solutions of magnesia is here indicated: first, the colloid hydrosilicate; then the hydrate; then again the hydro-

¹⁹ F. CIRKEL: *Asbestos*, p. 28, Fig. 6. Ottawa, 1905.

silicate; and then the main solution, or mixture of the two components. During consolidation and contraction of the last deposit, disassociation of the hydrate took place by diffusion into the shrinkage crevices near the middle of the vein. In fact, however, the separated deposits here found on the walls are probably, like those next to be described, derivatives from mixed solutions, by disassociation higher up the vein.

The most complex variety of composite veins is that represented in the illustration (Plate VI) and ordinarily found in proximity to laterite rich in magnesian silicates. It consists of a lamellation, in abundant repetition, of thin alternating sheets of chrysotile and retinalite, the thickest near the vein-wall and thinning outwardly; the first very thick layer of retinalite on the vein-wall is absent, having been broken from the specimen. In structure and development the variety is essentially identical with the lamellation of antigorite ("eozoon") in dolomitic limestone at Grenville, Canada, and other localities, although there the material of alternation with retinalite is calcite in place of chrysotile. In each case, I have concluded, a rhythmical process of unilateral vein deposition from laterite solutions has originally taken place—every pair of lamellæ comprising a film of colloid, magnesium hydrosilicate, with one of crystalloid, magnesium hydrate here and calcite in the Canadian occurrence, separated from the colloid by dialysis.

The rhythm of deposition has apparently been due to limitation of the flow into the vein fissure of the mixed solution of the two magnesian salts in meteoric waters to a certain period of accumulation, perhaps the rainy season of the year. After spreading upon the surface of the wall, disassociation began, the colloid being left clinging as a new coat upon the wall, while from its outer boundary—perhaps through a dried film serving as a septum—the crystalloid magnesium hydrate became diffused more or less completely by dialysis and so formed the companion coat of each pair of alternations. The amorphous magnesium hydrate readily crystallized into brucite, and this, by subsequent pressure—perhaps by rock strains, through expansion in neighboring portions of the mass—was converted into its fibrous variety, nemalite. Other fissures have been opened by contraction of the rock more or less transversely to this lamellation, but these have been generally filled with magnesium hydrate, amorphous and crystalline, as simple veins, changed in turn into nemalite by rock strains.

By later silicification or alteration under thermal conditions, all these lamellæ and transverse veins have become altered—nemalite into chrysotile-asbestos and deweylite into massive antigorite, in part retinalite.

CONCLUSIONS

In review, then, magnesia, in hydrated or carbonated condition, and deweylite and sepiolite, in colloid form, have always been the only magnesian derivatives from laterite, with tendency to early migration and transport, in virtue of their solubility.

Antigorite and talc, on the other hand, crystalline and never colloid, have merely served as insoluble fixatives to harden and record the transformations of their mobile and protean predecessors. Chrysotile is but a pseudo-fibrous variety of antigorite—in fact, a pseudomorph in antigorite after a pseudomorph in deweylite after nemalite, the fibrous form of brucite.

To the list of rock-making minerals, brucite, deweylite and sepiolite need to be added as important accessories.

The evidences in confirmation of these views from field observations, optical examinations, etc., together with a review of the literature of brucite, serpentine, antigorite, and the hydrous magnesian minerals, have been gathered for presentation in a separate monograph.

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COLUMBIA UNIVERSITY.



2017.07.10

● 2017年12月1日，中国银保监会发布《关于规范商业银行代理销售业务的通知》，自2018年1月1日起实施。该通知对商业银行代理销售业务进行了全面规范，旨在保护消费者权益，防范金融风险。

ANNALES N. Y. ACAD. SCI.

VOLUME XXIV, PLATE VI.

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A STUDY OF THE CHANGES IN THE DISTRIBUTION OF
TEMPERATURE IN EUROPE AND NORTH AMERICA
DURING THE YEARS 1900 TO 1909 ¹

BY HENRYK ARCTOWSKI

(Presented in abstract before the Academy, 2 February, 1914)

CONTENTS

	Page
Introduction.....	39
Long-range variations of temperature.....	41
European temperature data for 1900-1909.....	50
American temperature data for 1900-1909.....	73
Consecutive maps.....	87
Consecutive temperature curves for several stations in the United States..	97
About temperature variations and the changes of the arctic ice conditions.	104
Conclusions.....	111

INTRODUCTION

Considering the series of annual means of temperature, of given localities, we notice everywhere more or less important fluctuations. The curves expressing graphically the succession of figures show perfectly well pronounced variations at certain localities differing completely from other variations of other localities. Some curves go down while others go up, and the length of time separating the maxima varies from one curve to the other.

It is impossible, therefore, to discuss the question of climatic variations with only the data of a selected number of stations. All available data have to be taken into consideration, and the problem has to be studied geographically. The problem of the variations of terrestrial temperature is, indeed, absolutely similar to the problem of the mean elevation of the surface of the earth crust. The precision gained in the appreciation of the mean elevation of a continent depends on the precision of the utilized hypsometrical maps. The precision of an estimate of the mean depth of an ocean depends on the accuracy of the bathymetrical map, on the number of soundings. Since, in the case of temperature, we have also to deal

¹ Manuscript received by the Editor, 4 March, 1914.

with depressions below the average and elevations above, the knowledge of the extent of the areas covered by positive and negative departures is evidently more necessary for the discussion than the figures for some isolated stations, where the temperature conditions may or may not correspond to the average conditions of the surrounding countries.

The work done for a previous publication was the mapping of all the temperature data I could obtain for the years 1891 to 1900.

Considering the means of the decade, 1891-1900, as being quasi-normal values, I have formed for each year and each station the departures from these means. These annual departures have been inscribed on maps, and equideparture lines have been drawn. The areas of positive departures have been called thermopleions, the areas of negative departures, thermomeions or antipleions. The result of the discussion is that the year 1900 was a year of predominant thermopleions, the year 1893, on the contrary, a year of most predominant antipleions. Taking the probable areas into consideration, as well as the probable excess and deficiency of temperature, I found that the difference in temperature between these two years must have been at least $0^{\circ}.5$ C.

This was the main result of my memoir "*L'enchaînement des variations climatiques*,"² published in 1909. This practical demonstration of the fact that the temperature of the earth's atmosphere does not remain constant leaves a very important question open for discussion.

The annual departure maps of successive years showed in many cases some striking similarities in the mutual relationship of pleions and antipleions. I presumed, therefore, that pleions might persist from year to year and that they displaced themselves. In my further researches, I found it necessary to simplify the reasoning by adopting a way of expressing graphically the change of a given annual mean into that of the following year. To avoid the more or less regular annual variation, we have to take yearly means, but it makes no difference how we count the year, as long as we compare means of 12 consecutive months. By making consecutive yearly means for the one-year periods beginning with January, February, March and so on, and by comparing the curves expressing the succession of the figures, we can see how a negative departure of a given year passes progressively to a positive departure of another year.

I have published such consecutive temperature curves for the entire series of observations recorded in Batavia³ and New York,⁴ and portions

² HENRYK ARCTOWSKI: *L'enchaînement des variations climatiques*. Bruxelles, 1909.

³ *Op. cit.*, p. 32.

⁴ HENRYK ARCTOWSKI: On Some Climatic Changes Recorded in New York City. *Am. Geog. Soc. Bull.*, Vol. 45, p. 117.

of the curves for many other places are reproduced in this memoir. Two facts of some importance are clearly demonstrated by all these curves:

1) Although there are some most interesting agreements with the curve expressing the sun spot cycle, this cycle cannot be considered as being the main factor producing the pleionian variations, simply because the pleionian crests and depressions of the temperature curves repeat themselves three to four times more often than the maxima and minima of the solar curve.

2) The temperature curves for distant stations, belonging to absolutely different climates, present in certain cases such striking coincidences that it is impossible to ascribe them to simple chance circumstances. I may add that the consecutive curves of rainfall, of sunshine records and of atmospheric pressure display also pleionian variations and demonstrate the fact that we have to deal with more or less periodical alterations of the atmospheric circulation.

In order to make comparisons, a standard curve was necessary. The records of the exceptionally undisturbed climate of Arequipa, in Peru, gave this necessary standard.⁵

The consecutive temperature curve of Arequipa, for the years 1900–1910, shows four characteristic crests and four depressions. The curve of Bulawayo, in Rhodesia, is absolutely similar to the Arequipa curve. The same may be said about the curve obtained from the Mauritius observatory figures, and for Tananarive, Madagascar. Batavia, Java, displays also an indisputable resemblance with the Arequipa curve. North of the equator, Havana gives a similar curve, but the data of San Juan, Porto Rico, give a slightly retarded curve, and this is a most interesting fact. Indeed, the pleionian crests of Porto Rico could not be retarded if these temperature anomalies did not have a tendency to persist combined with a tendency of displacement.

The question, therefore, was whether all pleionian variations observed all over the world were not in immediate correlation with the Arequipa variation. Together with this question, it was necessary to solve the problem of the displacement of pleions.

LONG-RANGE VARIATIONS OF TEMPERATURE

The waves expressing the changes of temperature are of different amplitude and different length. If we take monthly means of temperature, we do not take into consideration the groups of cold and hot waves which characterize the changes of weather, and we eliminate also the short diurnal waves of the more or less regular daily variation. If we

⁵ HENRYK ARCTOWSKI: The "Solar Constant" and the Variations of Atmospheric Temperature at Arequipa and Some Other Stations. *Am. Geog. Soc. Bull.*, Vol. 44, p. 598.

take yearly means, the groups of exceptionally cold or exceptionally hot months are also eliminated, at least to a certain extent. In fact, in a yearly mean, of a normal value, the effect of a couple of abnormally cold months may be balanced by a couple of very hot months, so that the yearly mean of temperature may remain normal.

The advantage of consecutive twelve monthly means⁶ over the calendar yearly means is that we can detect the effect of some of the shorter waves on a yearly mean, giving us at the same time the possibility of locating seasonal anomalies. Likewise, if we take the consecutive means of groups of yearly means we will disclose, easier than in any other way, the successions of colder and warmer periods during various lengths of time.

Admitting, for the pleionian variations, a period of from two to five years as the unit of time, we will say that shorter climatic variations are *brachychrone* and those that are very much longer than these pleionian variations are *macrochrone*. Besides the ordinary pleions and antipleions or thermomeions, therefore, we will have to speak of *brachypleions* and *macropleions*, of *brachymeions* and *macromeions*.

The curves of the following diagram (Fig. 1) may serve to explain more clearly the difference between macropleionian, pleionian and brachypleionian waves.

The first curve shows the succession of consecutive annual means for Arequipa. A, B, C, D, are pleionian crests, preceded and followed by antipleionian depressions. With the exception of the second depression, which may have been accentuated by the presence of great quantities of volcanic dust in the higher layers of our atmosphere,⁷ the depressions, as well as the crests, show a striking tendency to decrease from 1901 to 1909.

⁶ I think that the expression "consecutive means" is just as comprehensible as the expression "overlapping means," "progressive means" or "moving averages."

WILLFORD I. KING, in his "Elements of Statistics" (New York, 1912, p. 166), uses exclusively the term "moving average."

As far back as 1841 LUKE HOWARD, "On a cycle of eighteen years . . ." (Philos. Trans. Royal Soc. of London for 1841, p. 277), utilized consecutive means and called them "averages on successive cycles."

H. H. CLAYTON, in his paper "A lately discovered meteorological cycle" (Am. Meteor. Journ., Vol. 1, p. 130, 1884), used the perfectly comprehensive expression "means of every twelve consecutive monthly means."

⁷ Many papers have been published recently, concerning the question of the influence on meteorological conditions of volcanic dust, present in the higher layers of our atmosphere. Some information upon the effect of this cause on the observed variations of the "solar constant" may be found in the following papers:

C. G. ABBOT: "Do volcanic explosions affect our climate?" (Nat. Geogr. Mag., Vol. 24, p. 181. 1913.) C. G. ABBOT: "The solar constant of radiation." (Trans. Internat. Union for co-op. in solar research, Vol. 3, p. 201. 1911.) C. G. ABBOT, F. E. FOWLE and L. P. ALDRICH: "The variation of the sun." (Astronomische Nachrichten, Vol. 194, p. 431. 1913.)

C. G. ABBOT and F. E. FOWLE: "Volcanoes and climate." (Smithsonian Miscellaneous Collections, Vol. 60, No. 29. 1913.)

The punctuated lines show this variation, which is absolutely distinct from the pleionian variation and may have a period of 18, 19 or any other number of years. The length of time makes no difference, the only important fact being that such a long range or macrochronic variation exists. By eliminating the effect of the pleionian variation, we obtain macropleionian crests and macromeionian depressions, but it is evident that for that purpose a long series of meteorological records is necessary.

FIG. 1.—*Diagrams of consecutive annual and consecutive monthly means of temperature at Arequipa*

On the other hand, the second curve of the diagram shows the succession of consecutive monthly means for the years 1906 and 1907 and displays brachypleions. In the case of Arequipa, the brachypleionian crests have a mean period of about 55 days.

If we were absolutely certain that the pleionian variations of the equatorial regions were due to changes of the energy radiated by the sun, it

HARVEST H. KIMBALL: "Solar radiation, atmospheric absorption, and sky polarization, at Washington, D. C." (Bull. Mount Weather Observatory, Vol. 3, p. 69. 1910.)

———: "The effect upon atmospheric transparency of the eruption of Katmai Volcano." (Month. Weather Review, Vol. 41, p. 153. 1913.)

———: "A return to normal atmospheric transparency." (Journ. Washington Acad. Sciences, Vol. 4, p. 17. 1914.)

W. J. HUMPHREYS: "Volcanic dust and other factors in the production of climatic changes, and their possible relation to ice ages." (Bull. Mount Weather Observatory, Vol. 6, p. 1. 1913.)

would be reasonable to restrict the use of the word antipleion to the meions due to purely dynamical causes and occurring during the pleionian years of the equatorial regions. In the present state of our knowledge of these variations, however, it is advantageous not to make a distinction between the direct and the mechanically provoked pleions and meions.

The graphic representation on maps of the positive and negative areas of long-range variations of temperature gives the position and extent of the macropleions and macromeions. In connection with the study of these maps, expressing long-range variations, the following problems have to be taken into consideration:

1) The existence of periods of a given number of years, as 18, 19, 35 or some other number, having been admitted, it is necessary to verify to what extent the variations of arbitrary selected stations may characterize long-range variations for a given country or, let us say, the question is to know whether macromeions and macropleions appear and disappear periodically.

2) Having admitted a presumably universal long-range variation, of about thirty-five years duration, Brückner has called exceptional regions (*Ausnahmegebiete*) some continental areas where the departures of lustra-means were opposite to the admitted variation. If such is the case, we should observe macromeions on these areas corresponding in time and location to macropleions of the universal variation. The question is whether the maps justify such a hypothesis.

3) Different authors, Blanford, Kremser, Lockyer, Hildebrandsson, Meinardus and Mossman among others, have noticed perfectly characteristic seesaw variations between given localities. In most of these investigations, only seasonal variations have been studied. Supposing, however, that there is no regular periodicity in the variations of long duration, we may ask whether there are corresponding areas of simultaneous occurrence of the macrochronic pleions and meions.

Satisfactory solutions of these three problems would advance very greatly our knowledge of the climatic changes. I even think that a scientific understanding of these changes would elucidate, to a great extent, some of the difficulties encountered in the study of these very much more important climatical variations which occurred in prehistoric times and which are studied from the point of view of geological records,⁸ and also such historical variations as those which, recently, have been most successfully studied by Ellsworth Huntington.

Unfortunately, the main difficulty lies in the lack of precision in our meteorological records. In order to discuss the long-range variations of

⁸ Die Veränderungen des Klimas seit dem Maximum der letzten Eiszeit. XI Intern. Geologen Kongress. Stockholm, 1910.

temperature in the United States, I took the tables of Frank H. Bigelow⁹ and, to my great astonishment, found that for some stations the departures of the annual means from the normal values are misleading.

The yearly mean temperatures of Chicago and Milwaukee, for example, illustrate my assertion. On Bigelow's tables the means of the first decade of years are $49^{\circ}.5$ and $45^{\circ}.7$ F. For the years 1873–1882 we have, therefore, a mean difference of $3^{\circ}.8$. The means of the last decade (1896–1905) are $48^{\circ}.3$ and $46^{\circ}.1$, figures which give a difference of only $2^{\circ}.2$. Considering decades of years, the increase is $0^{\circ}.4$ in Milwaukee, whereas there is a decrease of $1^{\circ}.2$ in Chicago. These stations are too close to one another to admit such a disagreement of figures, and it is evident that something is wrong in the records of either Chicago or Milwaukee. Of course, a difference of $1^{\circ}.6$ is not a very large figure and this difference may be due entirely to the variations of the town influences.

The records of Port Huron, Detroit and Toledo may serve as another example of misleading discrepancy. Considering again ten yearly means, the differences between the means of 1876–1885 and 1886–1895 are $0^{\circ}.1$ for Port Huron, $1^{\circ}.4$ for Detroit and $2^{\circ}.4$ for Toledo. It seems highly improbable that a decrease of temperature of $2^{\circ}.4$ could occur at Toledo simultaneously with a decrease of only $0^{\circ}.1$ at Port Huron. Now, comparing the departures of overlapping ten yearly means, departures from the general means or normals, we notice that one or two of these series of observations must certainly be considered non-homogeneous.

Likewise, the departures of Knoxville compared with those of Cincinnati, Memphis and Augusta show plainly that the records of Knoxville are unsatisfactory.

These examples demonstrate how cautious one has to be in dealing with long-range variations of temperature. The changes of the mean temperatures due to climatic variations of long duration are small and an apparently insignificant cause of error may modify the values of a series of observations to such an extent that the actual variation will be completely disguised. It is therefore easy to understand that even the best available figures—such as those of Bigelow's tables, for example—lead only to a sort of rough approximation.

I will pass now to the exposition and discussion of the results of my calculations.

On Bigelow's tables, there are fifty stations having continuous records from 1873 to 1905, but only five belong to the plateaux and Pacific coast, namely: Cheyenne, Denver, Portland, San Francisco and San Diego. In

⁹ Report on the temperatures and vapor tensions of the United States. U. S. Dept. of Agric. Weather Bureau, Bull. 8. 1909.

order, therefore, to have a better idea of the variations in the far western states, I had to take fourteen more stations whose records begin a few years later than 1873. I made, for these sixty-four stations, consecutive totals of ten-yearly means and the departures of these totals from the general or normal means of Bigelow's tables, and then I inscribed the figures so obtained on maps and drew the lines of equidepartures.

When one takes into consideration the fact that some of the departures are obviously wrong, the series of observations not being homogeneous, and when one looks on the maps and sees how far apart some of the stations are and how problematical these departures are, one arrives at the conclusion that all that may be said about long-range variations of temperature is to a great extent purely hypothetical.

It is undeniable that long-range variations exist, but a search for the periods of these variations is at present hardly justifiable, as an inspection of my maps demonstrates at once. The oscillations of temperature are indeed the product of a dynamical phenomenon, and it is of course only in the case of stationary oscillations that the phenomenon would be simple enough to allow the application of statistical methods to its study. Since, however, the phenomenon is dynamical, all (apparent) knowledge gained by a purely statistical treatment of the subject is defective and may be discarded, or must at least be considered as being an insufficient proof.

Let us examine the maps.

The departures for the decade of 1873-1882 give a map showing the existence of a macropleion covering practically all the area of the United States and extending most probably far north into Canada and south over the West Indies. Negative departures¹⁰ are to be observed along the Atlantic coast, in Boston, New York, Philadelphia and Wilmington, and also in San Diego, Calif. The positive departures are highest in Duluth, La Crosse, Chicago, Indianapolis, Cincinnati, Nashville and, farther south, in Key West, where the departure is $+ 0.9$ F. The highest figures are $+ 1.3$ in La Crosse and Cincinnati. The macropleion has a well marked crest extending NNW.-SSE.

During the following consecutive decades, this crest persists with a striking tendency to assume a N.-S. direction and, at the same time, we notice a slow displacement of the macropleion toward the south and the more or less gradual development of a macromeion in the west.

A radical change in this nearly stationary situation occurs between the decades 1877-1886 and 1878-1887. I reproduce the following four maps

¹⁰ The figures $- 0.3$ for Pittsburgh and Knoxville are considered as being evidently wrong.

to illustrate the fact (Figs. 2-5). These maps show perfectly a circular movement in a clock-wise direction. This displacement is gradual and the inspection of the maps leaves no doubt about the dynamic character of the climatic change. It also appears evident that the phenomenon is confined to the North American continent: the macromeion takes the place of the macropleion and both persist and stay on the continent: the macropleion has been pushed over the West Indies and Mexico in order to take the place of the macromeion over the western states, but has not been pushed away, over the Atlantic, toward Europe or Africa.

FIG. 2.—*Macropleion*. 1873-1882FIG. 4.—*Macromeion*. 1883-1892FIG. 3.—*Macropleion*. 1873-1882FIG. 5.—*Macromeion*. 1883-1892

The maps of the following consecutive decades again show a more or less stationary situation and a gradual development of the macromeion toward the south: for 1883-1892 the departures are already negative in the southern states and become more so for the decade 1885-1894. Hence, a rotary movement of this macromeion, similar to that of the macropleion of 1873-1882 and the following decades, would be expected. This, however, is not the case. The displacement occurs, but in a precisely reversed direction. The western macropleion spreads out toward the south, meets (1888-1897) a macropleion which progressively developed itself over the southern Atlantic states, and moves rapidly north.

From 1889-1898 until 1896-1905 we have once more a nearly stationary situation with a gradual and slow contra-clockwise pendulation. The following maps (Figs. 6-9) will serve to illustrate the progressive change which takes place.

Insisting once more upon the fact that, in many cases, the departures utilized are most problematical and that the maps must be considered to be very inaccurate, I cannot refrain from drawing some more conclusions gained from the inspection of these maps.

FIG. 6.—*Macropiection*. 1889-1898

FIG. 8.—*Macropiection*. 1895-1904

FIG. 7.—*Macropiection*. 1894-1903

FIG. 9.—*Macropiection*. 1896-1905

The following table (Table I) gives the highest and lowest departures for each decade of years. The corresponding totals show the amplitudes of the anomalies of temperature represented graphically on the ten-yearly maps. The highest figure is $1^{\circ}.7$ F. The amplitude of the macrochronic variation is therefore very small. In other words, as far as temperature is concerned, the changes of climate are restricted to narrow limits.¹¹ The smallest amplitude is 0.9 and not 0, as it ought to be, if we had to deal with regular seesaw movements.

¹¹ It is interesting to note that I have previously found a similar figure for Europe. The departure maps for the decades of 1851-1900 (*L'enchaînement des variations climatiques*, p. 38) show a highest amplitude of $1^{\circ}.1$ C. = $1^{\circ}.08$ F.

TABLE I.—*Extreme departures*

Decades	Highest and lowest departures		Difference	Mean
1873-1882.....	+1.3	-0.4	1.7	+0.45
1874-1883.....	+1.3	-0.4	1.7	+0.45
1875-1884.....	+1.2	-0.5	1.7	+0.35
1876-1885.....	+1.0	-0.4	1.4	+0.30
1877-1886.....	+1.2	-0.4	1.6	+0.40
1878-1887.....	+0.8	-0.4	1.2	+0.20
1879-1888.....	+0.7	-0.7	1.4	0.
1880-1889.....	+0.6	-0.9	1.5	-0.15
1881-1890.....	+0.5	-0.9	1.4	-0.20
1882-1891.....	+0.5	-0.9	1.4	-0.20
1883-1892.....	+0.6	-1.0	1.6	-0.20
1884-1893.....	+0.5	-1.0	1.5	-0.25
1885-1894.....	+0.6	-0.8	1.4	-0.10
1886-1895.....	+0.3	-0.7	1.0	-0.20
1887-1896.....	+0.3	-0.6	0.9	-0.15
1888-1897.....	+0.5	-0.4	0.9	+0.05
1889-1898.....	+0.7	-0.5	1.2	+0.10
1890-1899.....	+0.6	-0.6	1.2	0.
1891-1900.....	+1.0	-0.6	1.6	+0.20
1892-1901.....	+0.9	-0.6	1.5	+0.15
1893-1902.....	+1.0	-0.6	1.6	+0.20
1894-1903.....	+1.1	-0.8	1.7	+0.15
1895-1904.....	+0.7	-0.8	1.5	-0.05
1896-1905.....	+0.8	-0.7	1.5	+0.05

Now, if we take the column expressing the highest departures, or crests of the macropleions, we notice a well-pronounced variation of about nineteen years duration. The means of highest and lowest departures also display a difference of about nineteen years between the warmest decades.¹²

It is interesting to note that a period of nineteen years was advocated long ago by H. C. Russell¹³ and recently by William J. S. Lockyer.¹⁴

The figures of my table are too uncertain to serve as a strong argument in favor of Russell's period. I give them simply to illustrate a method of research which is highly recommendable.

To sum up the results obtained by the inspection of the maps, I will say that the long-range variations of temperature of particular stations in the United States are due to irregular pendulations of macropleions and macromeions, that these pendulations are complicated by the existence of slight seesaw movements (or vibrations) which increase or decrease the departures, making the macropleions more or less accentuated, and that, finally, the entire system of macropleions and macromeions moves up and down. This last movement is shown on the maps by an increase in size of the macropleions and a decrease of the macromeions or vice versa. This is the real long-range variation. The decade of

¹² The lustra means of the temperature observed in New York City demonstrate this variation very clearly. (Am. Geogr. Soc. Bull., Vol. 45, p. 124. New York, 1913.)

¹³ H. C. RUSSELL: "Meteorological periodicity" (Journ. Roy. Soc. of N. S. W., 1876, p. 151).

¹⁴ Solar Physics Committee. A discussion of Australian meteorology, p. 66. London, 1909.

1873–1882 is a typical example of a widely spread-out macropleion, while the decade of 1883–1892 shows a predominant macromeion.

The next problem to be taken into consideration is whether the maximal development of macropleions occurs simultaneously on the different continents.

I have already published the departure maps of the five decades from 1851–1900 for Europe,¹⁵ but I think that it would be useless to make comparisons without the aid of consecutive maps. Therefore it may be that the increase in temperature is simultaneous on both sides of the Atlantic or that, on the contrary, there are compensations,—it may also be that there are correlations in the movements of the macropleions or even pendulations of a higher order. I have to leave these questions unsolved. They concern the last and most important of the three problems of long-range climatic variations mentioned at the beginning of this discussion. I may venture to add that this is also the only problem which remains to be solved, because the second problem concerning long-range variations, mentioned above, does not harmonize with the dynamical conception of climatic variations which must be admitted.

EUROPEAN TEMPERATURE DATA FOR 1900–1909

It is really astonishing that after all the efforts which are made, all over the world, to organize and maintain meteorological stations, mainly for the purpose of collecting data, the actual results of the work which is done are as inaccessible as they are.

It seems to be a very simple matter to take into consideration the European temperature data for the years 1900–1909 in order to discuss the results, but it is not so. I had in view the yearly means of these years. One would think that in a town like New York City all the publications where these figures are recorded could be easily found. This is a mistake. In order to have the necessary data I had to obtain them by correspondence. I express therefore my thanks to the Directors of the different meteorological institutions who helped me in my work by providing me with the necessary data.

In the following tables (Table II) I give the annual means in form of departures from the means of the decade 1900–1909. All the figures are degrees centigrade.

¹⁵ *Op. cit.*, pp. 40–42.

TABLE II.—Temperature data for European stations¹

GREAT BRITAIN											1909	1908	1907	1906	1905	1904	1903	1902	1901	1900	Mean
0. Scotland, N.....											—0.4	+0.4	—0.1	+0.1	+0.3	+0.1	—0.3	—0.3	+0.3	+0.1	7.5
1. Scotland, E.....											—0.5	+0.3	—0.1	+0.1	+0.3	0.	—0.2	—0.4	+0.2	+0.1	7.6
2. England, N. E.....											—0.5	+0.1	—0.1	+0.1	+0.2	+0.1	—0.1	—0.4	0.	+0.2	8.7
3. England, E.....											—0.6	—0.1	—0.1	+0.5	+0.1	+0.1	+0.2	—0.4	—0.2	+0.3	9.3
4. Midland Counties.....											—0.6	0.	—0.1	+0.5	0.	—0.1	0.	—0.3	—0.1	+0.4	8.9
5. England, S. E.....											—0.6	0.	—0.1	+0.3	0.	0.	+0.3	—0.2	0.	+0.5	9.7
6. England, W.....											—0.6	+0.4	0.	+0.4	+0.2	0.	+0.1	—0.2	+0.1	+0.2	8.5
7. Scotland, N. W.....											—0.6	+0.1	—0.2	+0.2	+0.1	—0.1	+0.1	—0.3	+0.1	+0.3	9.0
8. England, N. W.....											—0.5	+0.1	—0.4	0.	—0.1	+0.1	+0.3	—0.1	—0.1	+0.3	9.7
9. South Wales.....											—0.2	+0.4	—0.1	0.	+0.3	+0.1	—0.1	—0.1	0.	+0.1	8.9
10. Ireland, N.....											—0.3	+0.4	—0.1	+0.2	+0.2	+0.1	—0.1	+0.1	—0.1	+0.1	9.7
11. Ireland, S.....											—0.3	+0.1	—0.1	+0.1	—0.1	+0.5	+0.1	—0.1	0.	+0.6	11.2
11. English Channel.....																					
NORWAY																					
Voss											—0.6	+0.6	—0.1	+0.5	+0.5	—0.2	+0.2	—0.6	+0.5	—0.4	5.3
Laerdal											—0.8	+0.5	+0.1	+0.5	+0.2	—0.1	+0.1	—0.6	+0.8	—0.2	6.3
Balestrand											—0.5	+0.4	—0.2	+0.3	—0.1	—0.2	+0.1	—0.5	+0.8	—0.3	6.6
Florø											—0.5	+0.5	—0.2	+0.4	+0.1	—0.1	+0.1	—0.9	+0.8	—0.1	6.9
Sundalen											—0.5	+0.5	+0.3	+0.5	0.	—0.2	+0.6	—0.7	+0.6	—0.7	4.0
Christiansund											—0.4	+0.3	0.	+0.2	+0.1	—0.3	+0.3	—0.6	+0.9	—0.7	6.5
Trondhjem											—0.4	+0.5	+0.4	+0.6	+0.4	—0.2	+0.6	—0.9	+0.4	—0.7	4.5
Brønnø											—0.4	+0.3	+1.0	+0.3	+0.2	—0.2	+0.5	—0.6	+0.9	—1.1	5.0
Hartfjeldalen											—0.6	+0.3	+1.1	+0.6	+0.1	—0.6	+1.3	—0.6	+0.6	—1.3	0.8
Bossmo											—0.3	+0.5	+1.1	+0.5	+0.2	—0.3	+0.8	—0.7	+0.3	—1.7	3.1
Bodø											—0.6	+0.1	+0.5	—0.1	0.	—0.2	+0.6	—0.6	+0.9	—1.0	4.0
Skomvær											—0.3	+0.4	+0.4	+0.1	+0.3	0.	+0.3	—0.6	+0.5	—0.8	4.6
Svolvær											—0.4	+0.2	+0.7	+0.3	+0.3	—0.1	+0.4	—0.7	+0.6	—1.2	4.1
Tromsø											—0.2	+0.2	+0.6	—0.3	+0.7	+0.1	+0.5	—1.2	+0.8	—1.0	2.3
Alten											—0.1	+0.3	+1.0	—0.1	+0.7	—0.3	+0.1	—1.2	+0.8	—1.6	0.7
Gjesvær											—0.2	+0.2	+0.7	—0.1	+0.8	+0.4	—0.1	—1.2	+0.8	—0.9	1.8
Mehavn											—0.2	+0.4	+0.8	+0.3	+0.4	+0.3	—0.1	—1.6	+0.3	—1.0	1.0
Vardø											+0.2	+0.4	+0.6	+0.5	+0.4	+0.3	0.	—1.6	+0.3	—0.8	0.8
Sydvaranger											+0.3	+0.3	+0.8	+0.5	+0.3	+0.1	+0.5	—1.8	+0.7	—1.3	—0.5
Torungen											+0.4	+0.4	+0.2	+0.5	+0.5	—0.4	+0.1	—1.0	+0.4	—0.7	7.1
Utsire											+0.4	+0.4	+0.2	+0.5	+0.3	—0.2	+0.5	—0.7	+0.4	—0.5	7.1
Nordøerne											+0.3	+0.3	+0.8	+0.3	+0.3	—0.4	+0.5	—0.6	+0.8	—1.1	5.5
Andenes											+0.3	+0.3	+0.7	+0.3	+0.3	—0.4	+0.5	—0.7	+0.4	—1.3	3.2
Røros											+0.7	+0.6	+0.7	+0.1	+0.1	—0.7	+0.5	—1.1	+0.5	—0.8	—0.6
Hjerkinn											+0.5	+0.5	+0.5	+0.1	+0.1	—0.4	+0.3	—0.9	+0.3	—1.1	0.0
Dovre											+0.6	+0.6	+0.5	+0.1	+0.1	—0.4	+0.2	—0.9	+0.7	—1.0	1.0
Granheim											+0.6	+0.6	+0.3	+0.1	+0.5	—0.4	0.	—1.2	+0.6	—1.0	1.8
Listad											+0.6	+0.6	+0.2	+0.1	+0.5	—0.4	+0.2	—1.0	+0.6	—0.5	2.5
Lillehammer											+0.4	+0.6	+0.2	+0.1	+0.9	—0.4	+0.3	—1.1	+0.6	—0.6	3.4
Rena											+0.4	+0.6	+0.3	+0.1	+0.2	—0.4	+0.3	—1.1	+0.6	—0.5	1.9
Hamar											+0.5	+0.5	+0.1	+0.1	+0.4	—0.4	+0.1	—1.4	+0.3	—0.6	3.5
Eidsvold											+0.6	+0.4	—0.1	+0.1	+0.5	—0.2	+0.4	—1.3	+0.1	—0.4	3.8

TABLE II.—Temperature data for European stations—Continued

	Mean	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Aabogen	3.6	—0.3	+0.1	—1.6	+0.4	—0.3	+0.3	+1.3	—0.1	+0.4	—0.3
Christiania	5.9	—0.3	+0.4	—1.2	+0.3	—0.1	+0.4	+1.0	—0.2	+0.5	—0.6
Aas	5.0	—0.5	+0.4	—1.2	+0.2	—0.2	+0.5	+0.9	—0.2	+0.5	—0.6
Krappeld	4.9	—0.3	+0.6	—1.2	+0.3	—0.1	+0.6	+1.0	—0.2	+0.4	—0.6
Færder	7.0	—0.5	+0.5	—1.1	+0.1	—0.3	+0.5	+0.8	—0.2	+0.5	—0.6
Nes	2.4	—0.7	+0.8	—1.0	+0.3	—0.4	+0.6	+1.0	+0.1	+0.2	—1.1
Veggli	2.8	—0.6	+0.5	—1.2	+0.4	—0.2	+0.8	+1.0	—0.2	+0.3	—1.0
Ulefos	5.1	—0.5	+0.2	—1.0	+0.2	—0.3	+0.5	+1.1	—0.3	+0.3	—0.5
Dalen	5.0	—0.6	+0.4	—0.9	—0.1	—0.2	+0.4	+1.0	—0.1	+0.5	—0.5
Austad	5.0	—0.3	+0.5	—1.1	0.2	—0.2	+0.5	+0.9	—0.2	+0.5	—0.7
Oksø	7.2	—0.5	+0.4	—0.9	+0.2	—0.2	+0.5	+0.7	—0.3	+0.5	—0.6
Eg	6.9	—0.4	+0.5	—0.8	+0.3	—0.1	+0.5	+0.8	—0.3	+0.6	—0.8
Mandal	7.0	—0.5	+0.4	—0.9	+0.3	—0.2	+0.3	+0.7	—0.2	+0.5	—0.7
Skudenes	7.4	—0.4	+0.6	—0.6	+0.2	—0.1	+0.3	+0.5	—0.1	+0.5	—0.4
Ullensvang	6.6	—0.2	+0.7	—0.6	0.2	—0.4	+0.1	+0.3	—0.1	+0.6	—0.7
Bergen	7.1	—0.4	+0.5	—0.6	+0.2	—0.1	+0.1	+0.4	—0.1	+0.6	—0.5
FINLAND											
Uleåborg	2.0	—0.9	+0.6	—1.8	+1.1	—0.2	+0.6	+0.7	+0.4	+0.1	+0.3
Kuopio	2.7	—0.7	+0.8	—2.1	+1.3	—0.6	+0.6	+1.2	—0.4	+0.2	+0.4
Vasa	3.6	—0.9	+0.3	—1.7	+0.8	—0.6	+0.5	+0.8	—0.1	+0.2	—0.1
Sordavala	3.0	—0.3	+0.8	—2.2	+1.2	—0.4	+0.8	+1.4	—0.7	0.2	+0.4
Tammerfors	4.0	—0.7	+0.8	—1.8	+1.1	—0.7	+0.6	+1.2	—0.5	+0.2	—0.2
Helsingfors	4.5	—0.6	+0.7	—1.6	+1.3	—0.5	+0.7	+1.1	—0.7	—0.2	—0.1
Marichamm	5.1	—0.5	+0.3	—1.4	+0.9	—0.5	+0.5	+1.1	—0.1	+0.1	—0.5
SWEDEN											
Lund	6.9	+0.3	+0.3	—1.0	+0.3	+0.3	+0.2	+0.8	—0.2	+0.1	—0.6
Kristianstad	7.5	0.1	+0.1	—1.2	+0.4	+0.1	+0.2	+0.9	—0.2	+0.1	—0.6
Karlshamn	7.0	+0.1	+0.1	—1.2	+0.4	0.1	+0.1	+0.9	—0.2	+0.2	—0.5
Kalmar	6.8	+0.3	+0.1	—1.5	+0.4	+0.2	+0.2	+1.0	—0.1	+0.2	—0.5
Halmstad	7.4	+0.2	+0.2	—1.1	+0.4	+0.2	+0.1	+1.0	—0.2	+0.3	—0.6
Vexjö	6.0	+0.4	+0.3	—1.2	+0.5	+0.1	+0.1	+0.9	—0.3	+0.1	—0.8
Visby	6.6	0.3	+0.7	—1.4	+0.4	—0.1	+0.4	+0.8	—0.3	0.4	—0.4
Göteborg	7.8	—0.3	+0.4	—1.1	+0.2	—0.1	+0.1	+0.9	—0.1	+0.4	—0.8
Vestervik	6.3	+0.2	+0.3	—1.3	+0.5	0.1	+0.3	+0.9	—0.2	0.2	—0.8
Jönköping	6.1	—0.1	+0.3	—1.1	+0.3	0.1	+0.5	+0.8	—0.2	0.4	—0.8
Venersborg	6.1	—0.2	+0.5	—1.2	+0.3	0.1	+0.2	+0.9	—0.2	+0.3	—0.7
Skara	5.3	—0.2	+0.5	—1.3	+0.5	—0.1	+0.2	+0.9	—0.2	+0.3	—0.7
Linköping	6.0	0.1	+0.5	—1.3	+0.4	—0.2	+0.4	+0.9	—0.2	+0.2	—0.5
Nyköping	5.8	0.2	+0.3	—1.7	+0.5	—0.2	+0.4	+0.9	—0.1	+0.3	—0.4
Asersund	5.3	—0.5	+0.6	—1.3	+0.4	—0.1	+0.5	+1.1	—0.3	+0.5	—0.8
Strömshad	6.6	—0.8	+0.7	—1.2	+0.2	—0.2	+0.3	+1.0	—0.1	+0.3	—0.6
Örebro	5.8	—0.9	+0.8	—1.5	+0.5	—0.1	+0.6	+1.0	—0.1	+0.3	—0.4
Stockholm	5.6	0.4	+0.8	—1.5	+0.7	—0.4	+0.5	+0.9	—0.2	0.4	—0.6
Karlstad	6.0	—0.4	+0.6	—1.4	+0.4	—0.2	+0.4	+0.8	—0.4	+0.4	—0.6

TABLE II.—Temperature data for European stations—Continued

	Mean	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Nora	4.7	-0.6	+0.5	-1.5	+0.6	-0.2	+0.6	+0.8	-0.2	+0.2	-0.6
Vesterås	5.5	-0.3	+0.7	-1.5	+0.6	-0.2	+0.5	+0.8	-0.2	+0.2	-0.5
Upsala	4.7	-0.3	+0.7	-1.8	+0.6	-0.3	+0.6	+1.0	-0.1	+0.1	-0.5
Falun	4.2	-0.4	+0.6	-1.6	+0.4	-0.3	+0.5	+0.9	+0.1	+0.4	-0.5
Gefle	4.4	-0.6	+0.3	-1.6	+0.5	-0.4	+0.9	+1.0	+0.1	+0.4	-0.3
Bjuråker	3.3	-0.5	+0.6	-1.5	+0.5	-0.5	+0.1	+0.8	+0.3	+0.4	-0.4
Sveg	1.1	-0.7	+0.5	-1.3	+0.4	-0.6	+0.1	+1.0	+0.5	+0.6	-0.6
Hernösand	3.2	-0.7	+0.9	-1.3	+0.6	-0.8	+0.1	+0.8	+0.3	+0.5	-0.1
Östersund	2.1	-1.0	+0.7	-0.9	+0.6	-0.6	+0.3	+0.8	+0.4	+0.3	-0.6
Storlien	0.4	-0.9	+0.7	-1.2	+0.6	-0.5	+0.1	+0.8	+0.4	+0.2	-0.7
Umeå	2.2	-1.2	+0.7	-1.6	+0.7	-0.9	0.1	+0.8	+0.9	+0.5	+0.2
Stensele	-0.2	-1.4	+0.7	-1.2	+0.7	-0.9	-0.1	+0.9	+0.9	+0.6	-0.2
Piteå	1.6	-1.2	+0.9	-1.6	+1.0	-0.7	+0.1	+0.9	+0.6	+0.5	-0.1
Haparanda	0.6	-0.7	+0.4	-2.1	+0.8	-0.4	+0.4	+0.7	+0.7	+0.3	+0.2
Jockmock	-1.1	-1.5	+1.0	-1.5	+0.2	-0.5	0.1	+0.7	+1.0	+0.7	+0.1
Gällivare	-1.1	-1.6	+0.9	-1.5	+0.4	-0.4	+0.3	+0.7	+0.9	+0.8	+0.1
Karesuando	-2.9	-1.5	+0.9	-1.6	+0.2	-0.5	+0.3	+0.4	+1.1	+0.8	-0.4
Häckeberga	6.4	+0.3	+0.1	-1.1	+0.4	+0.2	+0.2	+0.8	-0.2	+0.1	-0.7
Ronneby	6.6	+0.3	+0.1	-1.5	+0.4	0.2	+0.1	+1.0	0.2	+0.2	-0.5
Södra Mjönäs	6.2	+0.2	-0.1	-1.3	+0.5	0.2	+0.1	+0.9	-0.1	+0.2	-0.7
Klmmråla	5.2	+0.3	+0.2	-1.3	+0.6	0.	+0.2	+1.0	-0.1	-0.1	-0.6
Klmmared	5.7	0.	+0.8	-0.9	+0.5	0.	0.1	+1.0	-0.3	0.	-1.1
Kållerstad	4.8	+0.1	+0.2	-1.5	+0.8	0.	+0.1	+1.0	-0.1	+0.1	-0.7
Borås	5.5	-0.2	+0.4	-1.3	+0.4	-0.1	0.4	+0.9	-0.1	+0.4	-0.6
Kilanda	5.9	-0.2	+0.8	-1.4	+0.6	-0.1	+0.3	+1.0	0.2	+0.5	-0.9
Götlunda	5.4	-0.1	+0.4	-1.1	+0.5	-0.1	+0.4	+0.9	-0.2	+0.2	-0.7
Finspång	4.8	+0.1	+0.4	-1.2	+0.7	-0.1	+0.4	+0.8	-0.3	-0.2	-0.4
Farsta	5.0	-0.1	+0.4	-1.6	+0.7	-0.4	+0.5	+1.0	-0.2	-0.1	-0.6
Experimental fältet (Stockholm)	5.3	-0.2	+0.5	-1.7	+0.6	-0.3	+0.6	+1.1	0.2	+0.2	-0.5
Filipstad	4.4	-0.4	+0.4	-1.6	+0.4	-0.1	+0.5	+0.9	-0.2	+0.3	-0.4
Ulltuna	4.5	-0.3	+0.6	-1.7	+0.7	-0.2	+0.4	+1.0	0.3	0.	-0.4
Stjernsund	3.8	-0.7	+0.1	-2.0	+0.5	-0.1	+0.5	+1.1	+0.3	+0.5	-0.1
Ljungby	1.5	-0.5	+0.6	-1.2	+0.4	-0.5	+0.1	+0.9	+0.2	+0.6	-0.5
Sköldbäcka	3.0	-0.7	+0.4	-1.8	+0.4	-0.3	+0.4	+0.8	+0.4	+0.5	0.
Ramsjö	1.2	+0.5	+0.4	-1.5	+0.3	-0.7	+0.1	+1.0	+0.6	+0.4	-0.6
Slidsjö	2.8	-0.7	+0.7	-0.8	+0.7	-0.6	+0.2	+1.0	0.1	0.	-0.4
Quickjock	-1.2	-2.0	+1.2	-1.2	+0.2	-0.8	+0.3	+0.7	+1.1	+0.4	-0.2
DENMARK											
Skagen	7.7	-0.3	+0.4	-0.8	+0.3	0.	+0.4	+0.7	-0.1	+0.4	-0.5
Vestervlg	7.3	-0.2	+0.3	-0.9	+0.4	+0.1	+0.3	+0.6	-0.2	+0.4	-0.5
Fanø	7.6	+0.4	+0.3	-0.9	+0.4	+0.3	+0.3	+0.4	-0.4	+0.4	-0.7
Herning	7.2	+0.1	+0.2	-1.1	+0.4	+0.3	+0.3	+0.5	-0.3	+0.3	-0.6
Samsø	7.8	+0.1	+0.2	-0.8	+0.2	+0.3	+0.1	+0.7	-0.3	+0.1	-0.7
Kjöbenhavn (M. I.)	7.9	0.	+0.2	-1.0	+0.3	+0.2	+0.1	+0.7	-0.2	+0.1	-0.6
Bogø	7.7	+0.4	+0.3	-0.9	+0.3	+0.2	+0.1	+0.7	-0.3	0.	-0.7
Hammershus	7.6	+0.1	+0.1	-0.9	+0.2	+0.2	+0.1	+0.7	-0.3	0.	-0.5

TABLE II.—Temperature data for European stations—Continued

	Mean	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
SWITZERLAND											
Zürich	8.5	+0.7	-0.4	-0.2	+0.1	+0.7	0.	+0.3	+0.1	-0.4	-0.5
Bern	7.8	+0.8	-0.5	-0.1	-0.1	+0.8	-0.1	+0.3	0.	-0.4	-0.6
Basel	9.4	+0.8	-0.5	-0.3	+0.2	+0.7	0.	+0.3	0.	-0.5	-0.5
Genf	9.5	+0.8	-0.4	-0.2	0.	+0.7	0.	+0.3	0.	-0.2	-0.5
Lugano	11.2	+0.6	-0.5	0.	-0.1	+0.7	-0.3	+0.2	+0.2	0.	-0.4
Rigi	1.9	+0.4	-0.3	0.	+0.4	+0.9	-0.3	-0.2	+0.1	+0.3	-0.8
Säntis	-2.6	+0.5	-0.4	+0.2	+0.1	+0.7	-0.4	-0.2	0.	+0.3	-0.8
BELGIUM											
Ostende	9.6	+0.4	-0.2	-0.5	+0.4	+0.1	0.	+0.4	+0.1	-0.3	-0.4
Uccle	9.4	+0.4	-0.1	-0.6	+0.4	+0.2	0.	+0.5	0.	-0.2	-0.5
Arion	7.9	+0.9	+0.1	-0.3	+0.1	+0.4	-0.1	+0.3	-0.1	-0.3	-0.6
HOLLAND											
Groningen	9.4	+0.6	-0.2	-0.6	+0.2	+0.5	0.	+0.2	-0.3	-0.2	-0.6
Helder	9.6	+0.5	+0.2	-0.6	+0.4	+0.4	+0.2	+0.6	0.	-0.5	-0.8
De Bilt	9.9	+0.5	+0.1	-0.6	+0.3	+0.2	-0.1	+0.4	-0.2	-0.4	-0.5
Vlissingen	10.1	+0.7	+0.2	-0.4	+0.5	+0.4	-0.1	+0.3	-0.3	-0.5	-0.6
Maestricht	10.9	+0.8	+0.3	-0.1	+0.8	+0.4	-0.2	+0.1	-0.2	-0.6	-0.8
POLAND											
Warszawa	8.1	+0.7	+0.2	-1.2	+1.1	-0.2	+0.3	+0.7	-0.6	-0.6	-0.3
Silnica	7.6	+0.6	+0.1	-1.1	+0.5	+1.5	+0.2	+0.4	-0.5	-0.7	-0.4
Zabkowice	7.2	+0.6	0.	-1.2	+0.4	+0.3	+0.2	+0.5	-0.2	-0.6	-0.3
Sobleszyn	7.1	+0.8	+0.6	-1.1	+1.1	-0.4	+0.4	+0.7	-0.7	-0.7	-0.4
Plotrków	7.5	+0.4	+0.5	-1.3	+0.5	0.	+0.3	+0.7	-0.4	-0.6	-0.3
NORTHERN GERMANY											
Borkum	8.8	+0.4	+0.1	-0.8	+0.5	+0.5	+0.2	+0.6	-0.1	-0.2	-0.7
Wilhelmsbavn	8.3	+0.2	-0.2	-0.9	+0.5	+0.3	+0.1	+0.5	-0.2	-0.2	-0.4
Keitum	8.2	+0.2	+0.3	-0.9	+0.3	+0.3	+0.3	+0.4	-0.5	0.	-0.8
Hamburg	8.4	+0.4	-0.1	-1.0	+0.5	+0.3	+0.1	+0.7	-0.2	0.	-0.4
Kiel	7.6	+0.3	0.	-0.9	+0.6	+0.4	+0.2	+0.6	-0.2	0.	-0.6
Wüstrow	7.7	+0.5	+0.2	-1.0	+0.3	+0.3	+0.3	+0.7	-0.4	+0.2	-0.7
Swinemünde	8.0	+0.3	-0.1	-1.2	+0.6	+0.1	+0.3	+0.8	0.	+0.1	-0.2
Rügenwalde	7.2	+0.3	+0.2	-1.1	+0.6	+0.2	+0.4	+0.6	-0.3	-0.1	-0.3
Neufahrwasser	7.4	+0.5	+0.1	-1.2	+0.8	+0.1	+0.4	+0.6	-0.5	0.	-0.6
Memel	6.7	0.	+0.5	-1.3	+0.9	-0.5	+0.6	+1.1	-0.6	-0.1	-0.7
PRUSSIA											
Memel	6.6	+0.1	+0.6	-1.4	+1.0	-0.5	+0.6	+1.0	-0.6	0.	-0.5
Königsberg	7.0	+0.3	+0.4	-1.5	+1.0	-0.8	+0.4	+0.8	-0.4	-0.1	-0.5
Margrabowa	5.6	+0.4	+0.5	-1.5	+1.2	-0.5	+0.5	+0.9	-0.5	-0.2	-0.6
Osterode	6.9	+0.5	+0.3	-1.4	+0.8	-0.5	+0.3	+0.8	-0.5	-0.4	-0.2
Bromberg	7.8	+0.7	+0.4	-1.1	+0.8	0.	+0.3	+0.6	-0.5	-0.4	-0.5

TABLE II.—Temperature data for European stations—Continued

	Mean	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Kaiserslautern	8.7	+0.2	-1.1	-0.2	+0.5	+0.6	+0.4	+0.4	+0.1	-0.3	-0.4
Weissenburg	8.1	0.	-0.3	-0.5	+0.6	+0.7	+0.3	+0.4	+0.2	-0.6	-0.5
Regensburg	7.7	+0.1	-0.4	-0.4	+0.4	+0.8	+0.3	+0.2	+0.3	-0.5	-0.5
Passau	8.2	+0.4	-0.8	-0.1	+0.6	+0.8	+0.5	+0.3	-0.1	-0.6	-0.4
Landshut	7.6	+0.6	-0.3	-0.4	+0.2	+0.6	+0.2	+0.4	+0.2	-0.6	-0.4
Angsburg	8.2	+0.2	-0.4	-0.3	+0.4	+0.8	+0.2	+0.3	+0.1	-0.5	-0.5
München	8.1	+0.1	-0.4	-0.3	+0.4	+0.7	+0.1	+0.3	+0.1	-0.6	-0.4
Frauenstein	6.8	+0.6	-0.1	0.	+0.5	+0.8	+0.1	0.3	+0.1	-0.2	-0.8
Hohenpeissenburg	5.9	+0.5	-0.8	-0.2	+0.7	+0.9	-0.1	-0.3	+0.1	-0.4	-0.7
Tegernsee	7.3	+0.1	-0.4	-0.3	+0.4	+0.8	+0.2	+0.2	0.	-0.4	-0.5
Buchenau	5.4	+0.3	-0.1	-0.4	+0.2	+0.6	-0.1	+0.4	+0.1	-0.3	0.
Karlshuld	7.1	-0.7	-0.7	-0.4	+0.3	+0.8	+0.5	+0.1	+0.5	-0.6	-0.7
Bad-Reichenhall	7.8	+0.4	-0.4	-0.2	+0.3	+0.5	+0.1	+0.1	+0.2	-0.4	-0.7
Partenkirchen	6.6	+0.5	-0.3	+0.1	+0.3	+0.5	-0.1	-0.1	+0.2	-0.4	-0.7
Oberstdorf	5.9	+0.3	-0.4	0.	+0.2	+0.7	-0.1	0.	+0.1	-0.2	-0.8
BADEN											
Meersburg	8.6	+0.7	-0.4	-0.3	0.	+0.7	+0.1	+0.2	+0.1	-0.5	-0.4
Höchenschwand	5.3	+1.0	-0.5	-0.2	+0.2	+0.8	-0.2	+0.2	+0.1	0.	-0.6
Donaueschingen	6.1	+0.9	-0.5	-0.2	+0.1	+0.7	0.	+0.1	+0.2	-0.7	-0.7
Villingen	5.7	+0.8	-0.5	0.	+0.2	+0.6	+0.3	0.	0.	0.	-0.7
Todtnaubeurg	5.4	+0.9	-0.3	-0.1	+0.2	+0.7	-0.2	0.2	+0.1	0.	-0.6
Badenweiler	9.0	+0.7	-0.6	-0.5	+0.4	+0.5	0.	+0.5	+0.3	-0.6	-1.3
Freiburg	10.1	+0.8	-0.5	-0.2	+0.6	+0.7	0.	+0.2	+0.3	-0.7	-0.5
Gengenbach	9.3	+0.7	-0.3	-0.3	+0.3	+0.3	+0.2	+0.1	+0.2	-0.1	-0.7
Kniebis	5.7	+0.6	-0.3	-0.5	+0.3	+0.5	+0.3	+0.3	+0.1	-0.6	-0.5
Baden	9.3	+0.6	-0.3	-0.2	+0.3	+0.4	+0.3	+0.3	+0.2	-0.7	-0.5
Karlsruhe	9.8	+0.6	-0.3	-0.3	+0.3	+0.6	+0.3	+0.3	+0.2	-0.8	-0.7
Pforzheim	8.6	+0.6	-0.3	-0.3	+0.4	+0.6	+0.1	+0.5	-0.1	-0.6	-0.4
Mannheim	9.7	+0.6	-0.3	-0.4	+0.2	+0.4	+0.1	+0.2	0.	-0.7	-0.5
Heidelberg	10.2	+0.5	-0.4	-0.4	+0.3	+0.5	+0.1	+0.2	+0.1	-0.3	-0.5
Königstuhl	7.2	+0.5	-0.3	-0.5	+0.2	+0.5	-0.1	+0.2	+0.1	-0.6	-0.4
Buchen	7.7	+0.6	-0.6	-0.4	+0.4	+0.4	+0.1	+0.3	+0.1	-0.6	-0.4
Werthelm	8.7	+0.6	-0.3	-0.4	+0.5	+0.6	+0.2	+0.3	+0.1	-0.7	-0.4
SAXONY											
Leipzig	8.9	+0.4	-0.3	-0.9	+0.7	+0.5	-0.1	+0.5	-0.1	-0.4	-0.5
Zwenkau	8.0	+0.6	-0.1	-0.8	+0.6	+0.6	-0.1	+0.4	-0.1	-0.5	-0.3
Hubertusburg	8.4	+0.3	0.	-0.7	+0.9	+0.7	0.	+0.5	-0.2	-0.6	-0.6
Bautzen	8.4	+0.5	-0.1	-0.9	+0.7	+0.5	-0.1	+0.6	+0.1	-0.4	-0.5
Zschadras	8.6	+0.4	-0.4	-1.0	+0.6	+0.7	+0.1	+0.6	0.	-0.3	-0.3
Zittau	7.9	+0.4	-0.2	-1.0	+0.6	+0.7	+0.1	+0.4	0.	-0.5	-0.3
Grillenbourg	7.6	+0.3	-0.4	-0.7	+0.9	+0.7	+0.1	+0.3	-0.1	-0.5	-0.6
Freiberg	7.8	+0.7	-0.1	-0.7	+0.8	+0.5	-0.2	+0.3	-0.1	-0.5	-0.7
Schneeberg	7.2	+0.7	-0.2	-1.1	+0.9	+0.5	-0.1	+0.3	0.	-0.5	-0.6
Elster	6.3	+0.6	-0.4	-0.6	+0.7	+0.6	0.	+0.2	0.	-0.6	-0.5

TABLE II.—Temperature data for European stations—Continued

	Mean	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
WURTEMBERG											
Georgengrün	5.7	+0.6	-0.1	-0.4	+0.4	+0.6	-0.2	+0.4	-0.1	-0.6	-0.7
Altenberg	5.5	+0.5	-0.2	-0.9	+0.6	+0.6	-0.1	+0.5	-0.2	-0.7	-0.9
Reitzenhain	4.7	+0.5	-0.2	-0.8	+0.7	+0.5	-0.1	+0.4	0	-0.4	-0.6
Fichtelberg	2.7	+0.5	0	-0.8	+0.2	+0.7	-0.3	+0.4	+0.3	-0.3	-0.7
BIBERACH											
Biberach	7.6	+0.7	-0.5	-0.3	+0.3	+0.6	+0.1	+0.2	+0.2	-0.5	-0.6
Böttingen	5.3	+0.7	-0.5	-0.3	+0.1	+0.6	-0.1	+0.1	+0.1	-0.4	-0.5
Crailsheim	8.1	+0.3	-0.6	-0.5	+0.2	+0.5	-0.2	0	-0.1	-0.8	-0.7
Freudenstadt	6.6	+0.6	-0.4	-0.2	+0.3	+0.6	-0.3	+0.2	-0.2	-0.2	-0.5
Frickenhafen	7.4	+0.7	-0.5	-0.4	+0.4	+0.6	-0.1	+0.1	+0.2	-0.4	-0.6
Friedrichshafen	8.3	+0.7	-0.6	-0.3	+0.1	+0.6	+0.1	+0.1	0	-0.6	-0.5
Heldenheim	7.4	+0.7	-0.6	-0.3	+0.1	+0.6	+0.1	+0.1	+0.2	-0.7	-0.5
Hellbronn	9.7	+0.5	-0.4	-0.3	+0.3	+0.6	0	+0.3	+0.2	-0.8	-0.4
Hohenheim	8.4	+0.7	-0.4	-0.4	+0.3	+0.6	-0.2	+0.2	+0.3	-0.5	-0.5
Kirchberg	7.8	+0.7	-0.4	-0.4	+0.3	+0.6	-0.1	+0.2	+0.3	-0.7	-0.4
Mergentheim	8.4	+0.7	-0.4	-0.3	+0.3	+0.6	-0.2	+0.2	-0.1	-0.5	-0.5
Prevorat	8.3	+0.7	-0.4	-0.3	+0.3	+0.6	-0.1	+0.2	+0.3	-0.7	-0.4
Schömburg	7.8	+0.7	-0.4	-0.3	+0.3	+0.6	-0.1	+0.2	+0.3	-0.5	-0.5
Schopfloch	6.9	+0.7	-0.4	-0.4	+0.3	+0.6	-0.1	+0.2	+0.3	-0.7	-0.7
Stuttgart	9.9	+0.7	-0.4	-0.3	+0.3	+0.6	-0.1	+0.2	+0.3	-0.5	-0.6
Ulm	8.0	+0.7	-0.4	-0.3	+0.3	+0.6	-0.1	+0.2	+0.3	-0.5	-0.6
Willbad	7.6	+0.7	-0.4	-0.3	+0.3	+0.6	-0.1	+0.2	+0.3	-0.5	-0.6
Zell	6.9	+0.7	-0.4	-0.3	+0.3	+0.6	-0.1	+0.2	+0.3	-0.5	-0.6
AUSTRIA											
Böhm. Lissa	7.4	+0.4	-0.6	-1.1	+0.4	+0.7	0.6	1.1	0.1	-0.5	-0.4
Budweis	7.9	+0.5	-0.3	-0.8	+0.5	+0.5	0.7	0.2	0.1	-0.4	-0.5
Caslau	8.8	+0.4	-0.3	-0.9	+0.5	+0.5	0.2	0.2	0.2	-0.4	-0.4
Prerau	8.3	+0.6	-0.1	-0.9	+0.3	+0.3	0.2	0.2	0.1	-0.5	-0.2
Brünn	8.3	+0.7	-0.1	-0.9	+0.4	+0.4	0.2	0.2	0.1	-0.4	-0.4
Znaïm	8.5	+0.5	-0.2	-0.9	+0.3	+0.4	0.2	0.2	0.1	-0.4	-0.4
Olmütz	7.9	+0.6	-0.2	-1.1	+0.4	+0.4	0.2	0.2	0.1	-0.4	-0.4
Krakau	8.1	+0.6	-0.2	-1.1	+0.4	+0.4	0.2	0.2	0.1	-0.4	-0.4
Lemberg	7.6	+0.6	-0.2	-1.0	+0.4	+0.4	0.2	0.2	0.1	-0.4	-0.4
Czernowitz	7.8	+0.6	-0.2	-1.0	+0.4	+0.4	0.2	0.2	0.1	-0.4	-0.4
Wien	9.3	+0.5	-0.3	-0.9	+0.3	+0.3	0.2	0.2	0.1	-0.4	-0.4
Reichenau	8.5	+0.6	-0.3	-0.7	+0.4	+0.4	0.2	0.2	0.1	-0.4	-0.4
Semmering	6.1	+0.6	-0.3	-0.7	+0.4	+0.4	0.2	0.2	0.1	-0.4	-0.4
Kremsmünster	8.3	+0.6	-0.3	-0.4	+0.4	+0.4	0.2	0.2	0.1	-0.4	-0.4
St. Wolfgang	8.5	+0.6	-0.3	-0.4	+0.4	+0.4	0.2	0.2	0.1	-0.4	-0.4
Sonnblick	6.6	+0.7	-0.5	-0.3	+0.4	+0.4	0.2	0.2	0.1	-0.4	-0.4
Salzburg	8.5	+0.7	-0.3	-0.5	+0.4	+0.4	0.2	0.2	0.1	-0.4	-0.4
Graz	8.7	+0.5	-0.4	-0.6	+0.4	+0.4	0.2	0.2	0.1	-0.4	-0.4
Klagenfurt	7.7	+0.5	-0.4	-0.6	+0.4	+0.4	0.2	0.2	0.1	-0.4	-0.4
Neumarkt	6.7	+0.7	-0.2	-0.1	+0.4	+0.4	0.2	0.2	0.1	-0.4	-0.4

TABLE II.—Temperature data for European stations—Continued

	Mean	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Lalbach	9.3	+0.8	-0.5	-0.4	+0.3	+0.8	-0.2	0.5	-0.1	-0.7	-0.2
Gottschee	8.6	+0.6	-0.8	-0.4	+0.4	+0.9	-0.6	-0.5	+0.2	-0.4	+0.6
Görz	12.8	+0.7	-0.3	-0.4	+0.2	+0.9	-0.3	-0.2	+0.1	-0.3	-0.3
Abbazia	12.9	+0.5	0.0	-0.1	+0.3	+0.7	-0.3	-0.1	0.1	-0.3	-0.3
Pola	13.5	+0.6	-0.2	-0.2	+0.2	+0.7	-0.4	-0.2	-0.1	-0.5	-0.3
Lesina	16.1	+0.6	-0.2	0.0	+0.1	+0.4	-0.1	-0.3	-0.1	-0.3	-0.3
Innsbruck	8.2	+0.8	-0.3	-0.1	-0.2	+0.4	0.0	0.0	+0.1	-0.5	-0.4
Brinen	8.9	+1.0	-0.5	+0.1	-0.2	+0.1	-0.1	-0.2	+0.4	-0.2	-0.1
HUNGARY											
Akaszlatina	8.6	+1.5	+0.1	-0.7	+0.7	-0.1	-0.1	+0.2	-0.3	-0.8	0.1
Aknaugatak	8.3	+1.2	+0.1	-0.7	+0.5	0.0	+0.1	+0.3	-0.3	-0.8	+0.1
Arad	11.0	+0.7	-0.2	-0.8	+0.4	+0.2	+0.2	+0.3	-0.1	-0.5	+0.3
Budapest	10.1	+1.3	0.1	-0.9	+0.6	+0.4	+0.2	+0.3	-0.3	-0.5	+0.2
Bustyahára	8.9	+1.3	+0.2	-0.6	+0.8	+0.3	-0.1	+0.5	-0.6	-0.7	-0.1
Debreczin	9.7	+1.3	+0.2	-1.0	+0.7	+0.5	+0.1	+0.1	-0.7	-0.9	0.1
Eger	9.8	+1.2	+0.2	-0.8	+0.5	+0.7	-0.4	+0.1	0.7	-0.7	0.3
Flume	13.5	+0.6	-0.1	-0.2	+0.2	0.0	-0.4	-0.1	0.5	-0.3	-0.3
Görgény	9.1	+1.1	-0.2	-0.7	+0.4	+0.6	+0.1	+0.4	-0.1	-0.9	+0.1
Herény	9.6	+0.7	0.0	-0.6	+0.2	0.0	+0.3	+0.1	0.1	-0.6	-0.1
Kalocsa	11.2	+0.7	-0.1	-0.7	+0.5	+0.3	+0.1	+0.2	-0.1	-0.7	-0.1
Keszthely	11.0	+0.8	0.0	-0.6	+0.1	+0.3	+0.1	+0.1	+0.1	-0.6	-0.5
Kolozsvár	8.3	+1.2	-0.1	-0.6	+0.5	+0.1	+0.3	+0.5	-0.6	-0.5	-0.3
Nagy-Szeben	8.8	+1.6	-0.4	-0.8	+0.2	-0.3	-0.3	+0.4	-0.5	-0.2	0.2
Nemetboly	10.2	+0.7	-0.2	-0.6	+0.2	+0.3	+0.1	0.4	-0.1	-0.5	-0.3
Oszeplak	8.9	+0.7	-0.1	-0.6	+0.5	+0.6	+0.2	+0.2	-0.1	-0.8	-0.1
O'Gyalla	9.7	+0.5	-0.1	-1.0	+0.4	+0.5	+0.3	+0.2	0.1	-0.6	-0.3
Pécs	10.2	+1.1	0.0	-0.5	+0.5	+0.4	+0.1	+0.1	-0.1	-0.7	-0.3
Porsony	10.2	+0.7	-0.2	-0.9	+0.3	+0.3	+0.2	+0.2	+0.1	-0.5	-0.2
Schmenbanya	7.5	+0.7	0.0	-0.9	+0.3	+0.4	-0.1	+0.3	-0.3	-0.6	0.2
Szeged	10.9	+0.8	-0.4	-0.8	+0.4	+0.3	+0.1	0.3	-0.1	-0.6	+0.2
Turkeve	10.3	+0.7	-0.3	-0.8	+0.6	+0.4	+0.2	+0.3	-0.6	-0.9	0.1
Ungvár	9.4	+0.6	0.0	-1.0	+0.6	+0.3	0.0	+0.3	-0.4	-0.9	+0.1
Zágráb	11.2	+0.5	-0.3	-0.5	+0.3	+0.8	0.0	-0.2	+0.2	-0.6	+0.1
RUSSIA											
Kem	0.8	-0.5	+0.2	-2.6	+1.2	0.2	+0.9	+0.8	-0.1	+0.2	0.1
St. Petersburg	4.2	-0.5	+0.5	-2.2	+1.2	-0.2	+0.8	+1.2	-1.0	-0.4	+0.1
Pernau	5.3	-0.6	+0.7	-1.6	+1.5	-0.6	+0.7	+1.2	-0.8	-0.1	+0.2
Vindava	6.0	-0.1	+0.6	-1.2	+1.0	-0.5	+0.6	+1.0	-0.6	-0.2	-0.4
Souvalki	6.2	+0.4	+0.6	-1.5	+1.1	-0.4	+0.4	+1.0	-0.5	-0.3	-0.4
Warsaw	7.7	+0.6	+0.5	-1.2	+0.9	-0.2	+0.4	+0.8	-0.6	-0.5	-0.5
Pinsk	7.0	+0.5	+0.7	-1.1	+1.3	-0.6	+0.3	+0.9	-0.8	-0.5	-0.2
Vychnyi Volotchek	3.6	-0.4	+0.5	-1.4	+1.5	-0.4	+0.7	+1.4	-1.4	-0.9	+0.2
Koursk	5.6	-0.3	+1.1	-0.8	+1.2	-0.8	+0.7	+1.3	-1.2	-1.4	+0.2
Mezen	-1.0	-0.4	-0.4	-3.1	+1.0	+0.4	+1.8	+0.6	-0.2	0.0	+0.5

TABLE II.—Temperature data for European stations—Continued

	Mean	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Arkhangelsk	0.6	-0.7	-0.3	-2.9	+1.3	+0.1	+1.5	+1.0	-0.5	-0.3	+0.7
Kargopol	1.7	-0.6	+0.3	-2.4	+1.3	-0.1	+1.1	+1.1	-1.1	-0.4	+0.6
Vologda	2.8	-0.9	+0.2	0	+1.5	-0.1	+0.9	+0.9	-1.6	-0.4	+0.2
Totma	2.0	-0.6	+0.4	-1.9	+1.3	+0.1	+1.1	+1.3	-1.3	-1.1	+0.6
Ust-Sislolsk	0.4	-0.3	-0.3	-2.7	+1.1	+0.2	+1.4	+0.9	-1.0	-0.9	+0.9
Teherdine	0.3	-0.6	-0.6	-2.0	+0.8	+0.3	+1.4	+1.0	-0.8	-0.9	+1.1
Perm	1.4	-0.4	0	-1.3	+1.0	+0.6	+1.2	+0.8	-0.9	-1.8	+1.3
Ekaterinburg	1.2	-0.1	+0.7	-0.4	+0.7	0	+0.9	+1.2	-1.2	-2.3	+0.9
Onfa	2.8	-0.9	+0.8	-0.7	+1.3	-0.3	+1.1	+1.5	-0.8	-2.2	+0.7
Elabouga	2.9	-0.9	+0.9	+0.1	+0.6	-0.5	+0.5	+1.0	-0.8	-2.1	+1.1
Orenburg	4.0	-0.9	+1.0	+0.1	+0.5	-0.4	+0.5	+1.0	-0.9	-1.4	+0.2
Astrakhan	9.6	-0.9	+0.9	-0.4	+0.6	-0.2	+0.9	+1.1	-1.4	-1.2	+0.4
Rostow	9.8	-0.7	+1.3	-0.7	+1.2	-0.4	+0.6	+1.0	-1.3	-1.5	-0.1
Losovala	7.6	+0.2	+0.7	-1.0	+0.9	-0.2	+0.5	+0.7	-1.0	-1.1	0
Elisavetgrad	8.3	+0.6	+0.5	-0.9	+0.6	-0.3	+0.5	+0.8	-0.9	-0.9	+0.2
Nikoliev	10.2	+0.5	+0.8	-0.9	+0.2	-0.5	+0.3	+0.3	-0.8	-0.7	+0.5
Tarkhangout	11.5	+0.7	+0.7	-0.8	+0.3	-0.5	+0.2	+0.5	-0.7	-0.5	+0.9
Sebastopol	12.5	+0.3	+0.7	-0.7	+0.2	-0.3	+0.2	+0.4	-0.9	-0.7	+0.7
Novorossysk	13.0	+0.5	+1.0	-0.7	+0.2	-0.5	+0.2	+0.4	-1.0	-0.7	+0.1
Kazan	3.5	-1.0	+0.7	-0.8	+1.4	-0.5	+0.9	+1.3	-1.0	-1.0	+0.1
Odesa	10.1	+0.3	+0.5	-0.8	+0.7	-0.2	-0.7	+0.6	-0.8	-1.0	0
BULGARIA											
Sofia	9.8	+0.2	+0.1	-0.1	+0.6	0	0.2	-0.2	-0.6	0.3	+0.1
Lom	11.0	+0.4	+0.1	-0.4	+0.7	0.2	-0.3	+0.2	-0.3	+0.2	+0.5
Gabrovo	9.7	+0.8	+0.5	+0.1	+0.5	-0.3	-0.1	-0.1	-0.8	-0.2	+0.2
Obrostof	10.6	+0.6	+0.1	-0.4	+0.6	-0.2	0	-0.2	-0.6	-0.2	+0.3
Siliktra	11.6	+0.5	0	-0.5	+0.6	-0.3	0	+0.4	+0.2	-0.1	+0.2
Varna	11.7	+0.6	+0.5	-0.3	+0.5	-0.3	+0.1	-0.1	-0.7	-0.4	-0.1
Sliven	12.1	+0.5	+0.3	-0.1	+0.5	-0.2	+0.2	-0.1	-0.9	-0.4	+0.4
Kazanlıx	11.1	+0.6	+0.2	0	+0.6	-0.2	-0.3	-0.2	-0.7	0	+0.5
Plovdiv	12.3	+0.3	0	-0.2	+0.7	-0.1	-0.6	-0.2	-0.5	+0.1	+0.1
Haskovo	12.0	+0.1	0	-0.2	+0.5	+0.1	-0.1	-0.2	-0.6	+0.3	+0.4
RUMANIA											
Alexandria	10.7	+0.6	0	-0.5	+0.7	0	-0.2	-0.3	-0.6	-0.2	+0.1
Armaresti	10.0	+0.6	-0.2	-0.5	+0.5	-0.2	-0.2	+0.1	-0.6	+0.2	+0.4
Bala-de-Arama	9.2	+0.7	-0.2	-0.3	+0.5	-0.2	0	+0.1	-0.6	+0.3	+0.1
Barlád	9.6	+0.8	-0.1	-0.7	+0.4	-0.3	+0.2	+0.6	-0.7	-0.3	0
Botoshani	8.4	+0.9	+1.1	-0.9	+1.0	-0.7	+0.1	+0.8	-0.8	0.7	-0.5
Bralla	10.8	+0.6	-0.1	-0.7	+0.5	-0.2	+0.3	+0.1	-0.7	-0.3	0
Bucharest-Filaret	10.5	+0.6	-0.1	-0.5	+0.6	-0.1	+0.1	+0.6	-0.7	-0.1	+0.3
Buzau	10.3	+0.9	-0.1	-0.8	+0.3	-0.3	0	+0.2	-0.7	+0.2	+0.3
Calarasi	10.9	+0.9	+0.2	-0.3	+0.7	-0.4	-0.1	+0.5	-0.9	-0.5	+0.6
Campulung	8.1	+0.9	+0.2	-0.6	+0.5	-0.2	+0.1	+0.2	-0.6	-0.2	+0.5
Constantza	11.2	+0.8	+0.5	-0.5	+0.3	-0.6	+0.1	+0.6	-0.7	-0.6	-0.1
Corabia	11.0	+0.3	-0.1	-0.4	+0.6	-0.1	-0.2	0	-0.4	+0.1	-0.1

TABLE II.—Temperature data for European stations—Continued

	Mean	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Craiova	10.8	+0.7	+0.1	-0.4	+0.8	+0.2	-0.2	-0.1	-0.6	-0.3	-0.2
Doroholn	8.2	+0.8	+0.2	-0.0	+0.8	-0.6	+0.7	+0.4	-0.8	-0.5	-0.3
Draguseni	9.2	+0.7	-0.1	-0.7	+0.8	-0.3	0.	+0.4	-0.8	-0.3	0.
Falticeni	7.9	+0.7	-0.1	-0.8	+0.8	-0.0	+0.0	+0.4	-0.7	-0.4	-0.2
Focsani	9.0	+0.3	-0.4	-0.6	+0.7	-0.1	+0.2	+0.5	-0.8	+0.1	0.
Galatz	10.5	+0.0	+0.1	-0.6	+0.6	-0.2	+0.2	+0.7	-0.6	-0.4	-0.3
Ghimpati	10.2	+0.6	0.	-0.4	+0.8	-0.1	+0.1	+0.3	-0.7	-0.2	+0.1
Guirgin	11.2	+0.5	0.	-0.4	+0.7	0.	0.	+0.1	-0.7	-0.2	+0.2
Heresti	10.7	+0.5	-0.1	-0.6	+0.5	-0.1	0.	0.	-0.8	-0.1	+0.6
Jassy	9.6	+0.8	+0.2	-0.8	+0.8	-0.4	+0.2	+0.6	-0.9	-0.4	+0.2
Jascea	10.0	+0.7	+0.2	-0.6	+0.5	-0.2	+0.2	+0.5	-0.6	-0.3	+0.2
Mamorinta	7.9	+0.8	+0.4	-1.0	+0.9	-0.3	+0.6	+0.5	-0.9	-0.4	+0.2
Pamcesti-Dracom	8.0	+0.7	+0.2	-0.9	+0.5	-0.5	+0.4	+0.7	-0.9	+0.1	-0.3
Pitesti	9.4	+0.7	-0.1	-0.4	+0.6	+0.3	-0.9	+0.4	-0.6	0.	+0.3
Ploesti	10.3	+0.6	-0.2	-0.7	+0.3	-0.2	+0.2	+0.4	-0.8	-0.2	+0.6
Ramnacu-Sarat	10.3	+0.7	+0.1	-0.7	+0.5	-0.1	+0.3	+0.3	-0.7	-0.1	+0.1
Sinala	6.0	+0.7	0.	-0.4	+0.7	-0.1	+0.1	+0.1	-0.7	0.	-0.1
Strehala	9.8	+0.0	0.	-0.5	+0.4	0.	-0.2	+0.2	-0.4	0.	-0.1
Striharet	10.5	+0.7	-0.1	-0.5	+0.8	+0.1	-0.1	+0.1	-0.6	-0.3	-0.1
Sulina	11.0	+0.0	+0.7	-0.6	+0.3	-0.5	+0.2	+0.8	-0.7	-0.8	-0.1
Targu-Jiu	10.1	+0.8	-0.1	-0.3	+0.4	+0.1	0.	0.	-0.7	0.	0.
Targu-Ocna	8.7	+0.4	+0.2	-0.8	+0.8	-0.7	+0.3	+0.6	-1.0	0.	+0.4
Turn-Magurele	11.4	+0.4	0.	-0.3	+0.8	-0.3	-0.3	+0.1	-0.6	0.	+0.1
Turn-Severin	11.0	+0.3	-0.2	-0.5	+0.8	0.	0.	0.	-0.2	0.	-0.3
Vaslui	9.2	+0.6	0.	-0.5	+0.6	-0.3	+0.2	+0.5	-0.9	-0.2	-0.3

¹ Great Britain from the Weekly Weather Report, 1909, p. 434.
Norway from Jahrbuch d. Norwegischen Meteorologischen Instituts.
Finland from printed and manuscript data most kindly sent by Prof. G. Melander.
Sweden from Meteorologiska Jakttagelser i Sverige.
Denmark from the publications of the Danske meteorologiske Institut.
Switzerland from manuscript data received from the Schweiz. Meteorol. Centralanstalt.
Belgium from manuscript data obtained from the Observatoire Royal de Belgique.
Holland from manuscript data received from the Kon. Nederlandsch Meteorologisch Institut.
Poland from manuscript data sent by Dr. Gorczynski.
Northern Germany from manuscript data kindly sent by the Deutsche Seewarte of Hamburg.
Prussia from manuscript data obtained from the Koenigl. Preuss. Meteorologisches Institut.
Bavaria from manuscript data received through the courtesy of the Kgl. bayer. Meteorologische Centralstation.
Baden from manuscript data sent by the Zentral-Bureau für Met. u. Hydrographie im Grossherzogtum Baden.
Saxony from manuscript data kindly sent by the Königlich Sächsische Landes-Wetterwarte.
Württemberg from a clipping sent by the Kgl. Württ. Meteorol. Central-Station.
Austria from manuscript data sent by Prof. Trabert, Director of the K. K. Zentralanstalt für Meteorologie u. Geodynamik.
Hungary from manuscript data kindly sent by the M. Kir. Országos Meteorológiai és Földmágnésségi Intézet.
Russia, for the years 1900-1907 from the annals of the Observatoire Physique Central Nicolas and for the years 1908 and 1909 from the Resumé annuel of the Bulletin Mensuel, the Annals for these years having not yet been published in October, 1910, when these data were collected.
Bulgaria from manuscript data most kindly sent by Prof. Spas Watzof.
Rumania from manuscript data received from Prof. Heptles.

The records of France, Spain, Portugal, Italy, Servia, Turkey and Greece have not been taken into consideration. For Russia, Austria, Belgium, Holland and Switzerland I had only a small selection of data. For Russia, in particular, the number of utilized stations is absolutely insufficient.¹⁶ For Great Britain I have taken the district means. In reality, then, I have taken into consideration only Scandinavia and Central Europe, and European Russia simply for the sake of orientation.

It would seem that the figures of more than four hundred stations ought to give a very accurate idea of the variations of temperature which occurred during 1900–1909 in Central Europe.

This is true only to a certain extent.

First of all there are some local complications due to orographical conditions. To try to discuss these complications would lead me too far afield and would necessitate still more data.

I had in view simply to get a general idea of the geographical distribution of the annual departures of temperature and, for that purpose, I had just enough data.

The area covered by Scandinavia and Central Europe is absolutely insufficient to give the necessary maps for a clear understanding of the climatic variations which take place. Europe is but a fragment of an immense continent: the old world of Asia, Africa and Europe, and the variations of temperature which occur in Central Europe evidently depend on those which occur in Asia, in the Arctic regions, on the Atlantic and perhaps also of those which occur in Africa, in Equatorial Africa and the Sahara in particular. Central Europe is probably the least favorable spot on the earth's surface to be taken into consideration for the study of climatic variations. There, the variations are far too complicated to be understood easily. It would have been a great advantage to me, if I had had the data of all the Russian stations, those of Siberia and Turkestan in particular, and also the Indian data; but then I would have had to face such a number of new problems that it would have been quite impossible to stop the research work in order to write down the results obtained.

The ten European departure maps which I publish now (Figs. 12–21) are simply first material for further researches. These maps are most suggestive for many special investigations. In order to advance, however, I will avoid details as much as possible and will pass at once to the main question: the cause of pleionian variations.

¹⁶ It is my intention to study more in detail the variations of temperature which occurred during the years 1900–1909 in Poland, the Russian Empire and India as soon as circumstances permit.

Besides the Scandinavian countries, for which I had the complete record of observations, I had at my disposal the monthly means of temperature of Bucarest, Kazan, Warsaw, Odessa, Aachen, and Geneva. I made consecutive twelve monthly totals for these stations and also for Bodö, Sydvaranger, Haparanda, and Vestervig. On the following diagrams (Figs. 10 and 11) I reproduce these totals graphically, together with the curve of Arequipa, which will serve as a type of the direct solar variation in equatorial regions.

FIG. 10.—*Curves of the consecutive means at Bucarest, Odessa, Warsaw, Kazan and Arequipa*

The striking fact which is exhibited on these curves is that the variations of the European regions having a frankly continental climate are radically different from those which lie under the prevalent influence of the Atlantic. The curve of Kazan exhibits tendencies of increase of temperature followed by tendencies of decrease in regular successions, a variation repeating itself independently of the seasons of the year, just as in Arequipa. In Bucarest and in Warsaw we have also the typical pleionian variation. The curve of Aachen, on the contrary, is absolutely different. There we have small ups and downs entirely disfiguring the

pleionian curve. The Aachen curve is characterized by brachychronic variations of small amplitude.

In northwestern Europe, then, the brachypleions must have a predominant importance, whereas they do not affect eastern Europe very greatly. The curves of the Scandinavian stations, on the other hand, belong to a mixed type of pleions and brachypleions. Here we may have

FIG. 11.—*Consecutive temperature curves of Geneva, Aachen, Vestervig, Bodø, Haparanda and Sydvaranger*

a succession of several years during which the changes of temperature will be slow and great, as in Russia, followed by a succession of years of shorter and more irregular changes entirely different from those of Russia.

It would seem that there are pleionian and brachypleionian areas and that the border between them may temporarily belong to one area or the other. In reality, however, things are more complicated because the pleionian and brachypleionian variations are coexistent over more or less large areas. The comparison of the curves shows this very plainly.

If we now compare more closely the curves of Kazan, Warsaw, and Bucarest with the Arequipa curve, we notice sufficient similarities to grant that the primary cause of the Russian variations is most probably the same as that which produces the equatorial variations. The main cause of the complications in the geographical distribution of the excess and deficiency of temperature has to be ascribed to the perturbations of atmospheric circulation and transport of water vapor. We have to admit that if the value of the solar radiation changes, the temperature at the earth's surface must change; but the total atmospheric pressure remains the same. Consequently, a rise or fall of temperature must produce abnormal changes in the distribution of atmospheric pressure. These changes will affect the winds, the rainfall, and also the temperature. The normal, or let us say the Arequipa, variation of temperature must therefore undergo, in different regions, all sorts of modifications due to the local conditions of atmospheric circulation.

This fact explains the coexistence, and mutual dependence, of pleions and antipleions and explains also, to a certain extent, the persistence and more or less progressive displacement of the pleions from one region to another.

On the other hand, some, at least, of the brachypleions may be considered as peripheric trepidations of the pleions.

At present this interpretation is evidently but a simple working hypothesis for investigations yet to be made. It will, however, be sufficient to compare the curves of Aachen and the Scandinavian stations with those of figures 59 and 60 to arrive immediately at the conclusion that the brachypleionian oscillations are not at all a particularity characterizing the purely maritime climate of oceanic islands, as at first one would have been inclined to think.

The temperature scale not being indicated on the diagrams (Figs. 10 and 11) I give in the following table (Table III) the values of the highest and lowest consecutive means and their differences. These figures are °C. It would have meant too much work to reduce all the figures utilized to draw the curves into mean temperatures and into °C. The utilized figures are simply totals of twelve monthly means. In the case of °C. I added fifty to all figures in order to avoid the negative values of the winter months. For totals of °F. the figures of course give an apparently greater amplitude of variation to the curves. The preceding table will serve to make comparisons possible in case anyone would like to examine the amplitudes of individual crests. For my present purpose such comparisons are unnecessary.

TABLE III.—*Extreme values of consecutive means*

	Highest	Lowest	Difference °C.
Geneva	10.3	8.4	1.9
Aachen	9.7	8.2	1.5
Vestervig	8.3	6.1	2.2
Bodö	5.2	2.9	2.3
Sydvaranger	+0.8	−3.5	4.3
Haparanda	+2.1	−2.3	4.4
Bucharest	11.6	9.0	2.6
Odessa	11.9	8.4	3.5
Warsaw	9.3	6.4	2.9
Kazan	6.0	1.4	4.6

Passing now to the description of the maps, we will immediately realize the usefulness of the curves of consecutive means, because these curves eliminate the possibility of hazardous speculations about the displacement of the pleions from one year to another. Instead of such superficial considerations, we will find the way to study systematically the progressive transformation of the maps, a task which I cannot undertake at present not having the monthly means for all, or at least a large number of stations.

The map giving the distribution of the departures for 1900 (Fig. 12) is practically identical with the map of the same year I have traced, utilizing the departures from the means of 1891–1900.¹⁷ This demonstrates very clearly the fact that annual departures from ten yearly means serve perfectly to indicate the position and shape of pleions and antipleions.

On the present map the quasinormal line crosses Denmark, Southern Sweden, Curland, and forms a curve across Russia toward the Azof Sea. North and east of this line the departures are negative, south of it they are positive. The antipleion forms an immense wave with two centers of lowest values, one in Scandinavia, the other in Eastern Russia. In Sweden the greatest negative departure occurs at Quickjock and is −2.0 C. The Russian data do not permit of locating the eastern center of the antipleion exactly. In Kazan the departure is −1.0. The highest values of the pleion are +1.5, in Hungary. The pleion is broken up in central Europe by an area of low values. In southern Germany and Bohemia, the departures are below +0.5 and decrease to 0. along a line extending from the Belgian frontier into Bavaria.

The map of 1901 (Fig. 13) shows a radical change in the distribution of temperature. Where we had a negative wave we now have a positive wave. The pleionian departures are +1.2 in Swedish Lapland and +1.3 in southern Russia. The quasinormal line goes from Great Britain across Germany and Austria towards Rumania. The lowest departures of the antipleion are −0.7 in Erfurt and −0.8 in Gottschee, in Krain.

¹⁷ *Op. cit.*, p. 121.



FIG. 12.—Temperature departures for the year 1900

FIG. 13.—Temperature departures for the year 1901

FIG. 14.—*Temperature departures for the year 1908*

FIG. 15.—*Temperature departures for the year 1903*

Naturally one asks whether the antipleion of 1900 went down or the pleion went up. The consecutive curves will give some indication about the displacement which took place: The pleionian crest passed Kasan at the consecutive mean: Sept. 1900–Aug. 1901. In Haparanda, Bodö and Sydvaranger the crest occurs at the mean of Nov. 1900–Oct. 1901. In Vestervig and Aachen, Feb. 1901–March 1902.

We must admit therefore that, most probably, the displacement went from northeast to southwest, but the map shows the existence of an antipleion over the White Sea. Moreover, in 1901, the consecutive curve of Kazan is on the descent. The same is true in northern Scandinavia. If we consider the dates of the occurrence of the minimum, we find: Sydvaranger, Haparanda, Bodö, November, 1901–October, 1902; Kazan, 1902; Vestervig, Warsaw, Bucarest, February, 1902–January, 1903; Geneva, May, 1902–April, 1903. There is, therefore, a progressive invasion of a negative wave coming from the White Sea and spreading out towards the southwest and south. The map of 1902 shows plainly the importance of this antipleion.

This characteristic antipleion, with a departure of — 3.1 at its center in Mezen, follows closely the first depression of Arequipa. Therefore, a detailed study of the meteorological phenomena of 1902 would be most instructive if one took, besides the European data, those of Asiatic Russia and India. The distribution of the equideparture lines on the map (Fig. 14) shows plainly the dynamical character of the phenomenon.

It would not be very difficult to find out how this antipleion invaded Europe and the reason why could be traced as well, and correlated with the equatorial variation of temperature.

The map (Fig. 15) of the departures for 1903 is just as interesting as the map of 1902. There is an important rise of temperature over all the area with the exception of southwestern Europe, Ireland and Scotland. Now there is a pleion centered over Russia, where the departures are + 1.5 in Pernau, Vologda and Vychnyi Volotchek.

What became of the antipleion of 1902? Did it go towards the Atlantic and the south, or was there a rise of temperature *in situ* without any displacement?

The consecutive curve of Geneva (Fig. 11) shows that the antipleion of 1902 certainly did not cross Switzerland to go south; but the curves of Sydvaranger and Haparanda are very steep immediately after 1902, the curve of Warsaw (Fig. 10) shows a regular and progressive ascent from 1902 until 1903, while the curve of Bucarest, on the contrary, shows a slow ascent followed by a very much faster increase of temperature towards the end, and there the values remain high till the mean of

FIG. 16.—*Temperature departures for the year 1904*

FIG. 17.—*Temperature departures for the year 1905*

FIG. 18.—Temperature departures for the year 1906

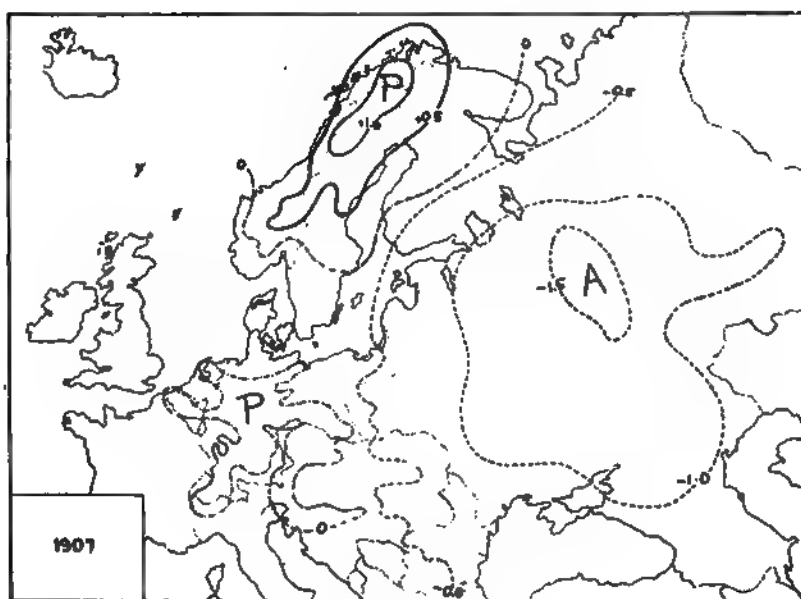


FIG. 19.—Temperature departures for the year 1907

September, 1903–August, 1904. Consequently, consecutive maps would show that the formation of the pleion began in the north and extended progressively south or southeast.

The map of 1904 (Fig. 16) shows a distribution of the equideparture lines similar, to a certain extent, to that of 1901; but the sign of the departures is reversed, since we have now an antipleion where we had a pleion in 1901. The consecutive curves are again a great help towards the understanding of what happened. If we consider this depression of temperature as being due to the same cause as that of Arequipa, we may say that in Kazan the reaction is felt first, then in Warsaw and finally in Bucarest, where it is very much retarded.

In Scandinavia the phenomenon appears to be more complicated. There we have two distinct depressions. One is coincident with that of Arequipa, as the curve of Vesterwig shows, and the other is greatly retarded. It may be that the second depression of Haparanda and Sydvaranger is due to a propagation of the antipleion first formed in Russia.

The map of 1905 (Fig. 17), if considered from the same point of view, represents the formation of a pleion and that of 1906 shows the same pleion after the maximum of its development.

The most important crests on the curves of Kazan and Bucarest occur between 1905 and 1906 and correspond to an Arequipa crest. In Warsaw we notice fluctuations; the same in Scandinavia, where they are even more pronounced. This pleion must have been Asiatic.

In 1907 (Fig. 19), there are residual pleions over Scandinavia and central Europe and an antipleion over Russia.

Between 1907 and 1908 the curves of Warsaw, Bucarest and Geneva show the Arequipa crest.

This fact demonstrates that the Russian antipleion did not spread out progressively over central Europe, as a comparison of the maps of 1907 and 1908 seems to indicate. On the contrary, an important interruption occurred, during which a brachypleion (corresponding to the Arequipa crest of 1907–1908) came from the south and invaded southern and western Europe without affecting the Russian antipleion. Finally, this Russian antipleion of 1908 went west in 1909 (Figs. 20 and 21). The consecutive curves, the curve of Geneva in particular, leave no doubt about this fact.

The main result gained by the study of the maps is that, during the years 1900 to 1909, the pleions and antipleions did not move from the Atlantic across Europe towards Asia. On the contrary, the displacement was from the northeast towards the southwest, or from the east towards the west. Moreover, these displacements did not cross the areas

FIG. 20.—*Temperature departures for the year 1908*

FIG. 21.—*Temperature departures for the year 1908*

of maritime climate. One may say, therefore, that the big pleionian variations of Europe are a purely continental and, perhaps, Arctic phenomenon.

It would be premature to attach any importance to the locations of origin of particular pleions. The areas where they are formed, *in situ*, are probably not always the same. Besides, the question whether a pleion is of an Asiatic or arctic origin has no importance for the present, simply because it would be absolutely premature to discuss the reasons why, under the influence of a temporary increase of solar radiation, one location of the polar or temperate regions is more favored than others.

It is evident that a temporary increase of energy radiated to the earth's surface, during, let us say, three months in succession, will not directly influence the temperature of the arctic regions if it occurs during the winter months of the northern hemisphere, whereas the antarctic regions will be greatly influenced.

The question of the formation and development of pleions, outside the equatorial regions, must be studied together with the seasonal changes of atmospheric pressure and the temporary alterations of atmospheric circulation, nebulosity, rainfall, etc. I intend to make such a study for particular pleions and especially for brachypleions. The fact, however, that in Russia there are some striking coincidences between the formation of pleions and the crests of the Arequipa curve is a most convincing proof of a common cosmical cause of these variations.

AMERICAN TEMPERATURE DATA FOR 1900-1909.

Since the equatorial or Arequipa variations of temperature can be observed not only in Russia but also along the Atlantic coast of the United States, in New York in particular,¹⁸ it was really fascinating to follow more closely the changes in the distribution of temperature which occurred simultaneously in different regions of the North American continent. Here, it was possible to follow the phenomenon from ocean to ocean, over a much more extensive area than that of central Europe, and, this area being more isolated, it is self-evident that more definite results were obtainable.

A research, apparently similar to mine, was made long ago by Helm Clayton.¹⁹ It was only after my investigations were nearly completed that I noticed the fact and Clayton's writings have therefore not at all influenced my work. Clayton studied the monthly departure maps pub-

¹⁸ H. ARCTOWSKI: "On some climatic changes recorded in New York City." Bull. Amer. Geogr. Soc., Vol. 45, p. 117. New York, 1913.

¹⁹ H. HELM CLAYTON: "Weather changes of long period." Amer. Meteor. Journ., Vol. 2, p. 126. Detroit, 1885.

lished in the Monthly Weather Review of 1884 and 1885, and for the sake of comparison I give his conclusions below.²⁰ The results I have obtained so far are so different from those of Helm Clayton that it is perhaps necessary to insist once more upon the fact that my maps are annual departure maps, whereas the maps utilized by him were monthly departure maps. Even in the case of monthly maps of temperature, however, Clayton's generalizations must be considered as simply plausible hypotheses, which may disagree with the observed facts. The departure maps for the months from August to November, 1912 (see Monthly Weather Review), will serve as an example.

The method of research I have adopted is evidently the same as that of Clayton²¹ and the pleionian variation, of equatorial regions in particular, is certainly the same phenomenon as the meteorological cycle of twenty-five months' duration discovered by Clayton,²² or the longer cycle, of about three years, advocated by Lockyer and others.

Though the method of using consecutive means, and tracing departure maps, has already been used long ago, it has not yet been applied to the scientific study of climatic variations in a sufficiently extensive and careful way to lead to the results of general interest and practical application which we might expect to obtain.

Before entering into the details of the description of the departure maps of the years 1900 to 1909, I will take into consideration the geographical repartition of the range of variation of the annual means of temperature.

On Bigelow's tables²³ I have formed the differences between the high-

²⁰ "1. There are areas of barometric depression, and elevation, which occupy weeks and months in their movements across the continent from West to East.

"2. There exist, independent of the movements of areas of barometric depression, and elevation, numerous seesaw oscillations in the pressure which have been given the name of surges.

"3. In front of and to the south of areas of barometric depression of slow movement and long duration, as in those of rapid movement and short duration, the temperature is above the normal; and below the normal north of them and in their rear which is usually the front of barometric elevations. In front of, and to the south of, areas of barometric elevation of long period, as in those of short period, the temperature is below the normal, and above north of them and in their rear which is usually the front of depressions. (In winter the area of warmth approaches and usually includes the area of lowest pressure, and the area of cold approaches and usually includes the area of highest pressure; in summer, vice versa.)

"4. In front of, and within, barometric depressions of long period, as in those of short, the rainfall is above the normal, and below, in their rear. In front of, and within, barometric elevations of long period, as in those of short, the general tendency is towards fair and clear weather with deficient rainfall."

²¹ HENRY HELM CLAYTON: "A proposed new method of weather forecasting by analysis of atmospheric conditions into waves of different lengths." *Monthly Weather Review*, 1907, p. 161. See also:

HENRY GAWTHROP: Temperature curves (*Ibid.*, p. 576).

²² *American Meteorological Journal*, Vol. 1, p. 130. 1884.

²³ *Op. cit.*, Bull. 8.

est and lowest annual means. The geographical distribution of these figures is most interesting. The highest differences are those of Bismarck, Duluth, St. Paul and Marquette. The figures are respectively $9^{\circ}.8$, $9^{\circ}.7$, $9^{\circ}.5$, and $9^{\circ}.4$ F. In North Dakota and the Lake Superior region the range of possible variation of the annual means is therefore above 9° F. From that region, the values diminish progressively towards the east, south and west. The line limiting the region where the differences are above 5° goes from Portland, Ore., towards Salt Lake City, North Platte, Hannibal, Lynchburg and from there northeast, along the Atlantic coast. The difference $7^{\circ}.2$ for Portland, Me., is too high. The series of observations taken in Portland, Me., is evidently not homogeneous. The values of $5^{\circ}.5$ for Los Angeles, $5^{\circ}.8$ for El Paso and San Antonio are also probably too high, since the line of 4° goes from Eureka southward over Sacramento toward San Diego, then eastward towards Little Rock, Memphis, Atlanta and Wilmington.

The lowest value, $3^{\circ}.1$ for San Francisco, and the value $2^{\circ}.8$ for the shorter series of observations of Corpus Christi and Jupiter, are not very much higher than the differences $2^{\circ}.1$ and $2^{\circ}.6$ of the pleionian crests and antipleionian depressions of the consecutive curves of Arequipa and Bulawayo. It follows that if, all over the United States, the variations are primarily due to pleions, having the same cause as the equatorial pleions, the phenomenon would be four times more pronounced at the center of the North American continent—in Winnipeg, let us say—than under the equator. Of course, in the case of the brachypleions, the difference would probably be very much greater, and if the results obtained from the study of the interdiurnal mean variabilities of temperature²⁴ are taken into account we must be impressed by the similarity of the results obtained. Evidently, the continentality must have the same exaggerating effect on climatic variations that it has on the cold and warm waves characterizing the changes of weather.

I will pass now to the study of the annual departure maps.

The figures utilized have been taken from the Annual Reports of the Weather Bureau and those of the Canadian stations were copied from the Summaries of the Monthly Weather Review. In Table IV, I reproduce the means of the decade 1900–1909 and the annual departures from these means for all the utilized stations. These figures were inscribed on maps and equideparture lines drawn. The ten maps thus obtained are reproduced as figures 22–31.

²⁴ J. HANN: "Untersuchungen über die Veränderlichkeit der Tagestemperatur." Sitz. Math. Nat. Cl. Acad. Wiss. Wien, Vol. 71, II, p. 571. Wien, 1875.

TABLE IV.—Temperature means (°F.) for the decade 1900-1909 and annual departures from these means.
Canada and the United States¹

	Mean	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Sydney	42.5	+0.6	+2.1	+1.7	-0.0	-1.9	-1.9	+0.6	-1.0	+0.8	+1.1
Halifax	42.2	+1.4	+2.0	+1.4	+0.2	-2.5	-2.0	+0.7	-1.8	+0.4	+0.3
Grand Manan	43.0	+1.2	+0.7	+0.8	+0.8	-1.8	-1.4	+0.3	-2.0	+0.3	+1.1
Yarmouth	43.0	+1.4	+1.2	+0.8	+0.8	-2.1	-1.9	+0.3	-1.8	+0.3	+1.1
Charlottetown	42.1	+1.3	+2.4	+1.7	-0.2	-1.6	-0.7	+0.8	-1.3	+0.4	+0.3
Chatham	40.5	-0.6	+0.7	+0.7	+0.5	-2.2	-0.6	+0.4	-1.4	+0.4	+0.3
Father Point	38.7	+0.5	+1.3	+0.6	+0.1	-3.0	-0.8	+1.0	-1.4	+0.6	+0.4
Quebec	39.0	+0.5	+1.0	+0.8	+0.3	-3.2	-1.4	+1.1	-1.3	+0.6	+0.4
Montreal	42.4	+1.5	+0.5	+0.3	+0.4	-3.1	-0.7	+1.3	-1.3	+0.8	+0.1
Kingston	43.4	+1.6	+0.4	+0.3	+0.4	-2.5	-0.3	+1.0	-1.3	+0.8	+0.1
Toronto	45.1	+1.3	+0.4	+0.3	+0.4	-2.4	-0.2	+1.3	-1.3	+0.8	+0.1
Fort Stanley	41.8	+1.6	+0.4	+0.3	+0.4	-2.4	-0.2	+1.3	-1.3	+0.8	+0.1
Perry Sound	43.1	+1.3	+0.4	+0.3	+0.4	-2.4	-0.2	+1.3	-1.3	+0.8	+0.1
Fort Arthur	38.2	+1.6	+0.4	+0.3	+0.4	-2.4	-0.2	+1.3	-1.3	+0.8	+0.1
Winnipeg	35.9	+1.0	+0.4	+0.3	+0.4	-2.4	-0.2	+1.3	-1.3	+0.8	+0.1
Minnedosa	35.3	+1.2	+0.4	+0.3	+0.4	-2.4	-0.2	+1.3	-1.3	+0.8	+0.1
Medicine Hat	42.6	+1.0	+0.4	+0.3	+0.4	-2.4	-0.2	+1.3	-1.3	+0.8	+0.1
Swift Current	38.6	+1.4	+0.4	+0.3	+0.4	-2.4	-0.2	+1.3	-1.3	+0.8	+0.1
Calgary	36.1	+0.5	+1.1	-0.2	-0.4	-1.0	+0.0	+1.6	-2.8	+2.1	-1.3
Battleford	34.6	+0.3	+1.1	-0.3	-0.8	-1.2	+0.0	+1.2	-2.1	+2.6	-2.4
Hamilton, Bermuda	60.0	0.	+0.5	-0.3	+0.5	+0.1	+0.0	+2.3	0.	+0.0	0.
Albany, Tex.	64.1	+0.3	+0.9	+0.6	-2.0	+0.6	-2.0	-1.3	+1.6	+0.6	+1.0
Albany, N. Y.	46.1	+2.0	+0.4	-0.1	+0.3	-2.7	-0.6	+0.5	-1.2	+0.0	+0.7
Alpena, Mich.	42.6	+1.5	-0.1	+0.6	0.	-2.8	-0.3	+1.2	-1.4	+0.0	+0.7
Amarillo, Tex.	56.1	+0.1	0.	+0.3	-1.1	+0.0	-0.3	-0.7	+1.3	+0.7	+0.5
Atlanta, Ga.	60.9	+1.0	-1.5	+0.2	-0.8	-0.7	-0.4	+1.3	+0.8	+0.8	+0.8
Atlantic City, N. J.	52.2	+1.6	-0.8	+0.2	+0.2	-2.0	-0.5	+0.3	-1.2	+0.8	+0.8
Augusta, Ga.	63.9	+0.6	-1.7	+0.2	-0.7	-0.7	+0.1	+0.3	+0.5	0.	+0.3
Baker City, Oreg.	46.2	+2.0	+0.6	-0.2	-1.2	+1.0	-0.3	-0.2	+0.5	+0.0	+0.3
Baltimore, Md.	55.0	+1.1	+0.6	+0.2	0.	-2.4	-0.6	+1.0	-1.4	+1.0	+0.3
Binghamton, N. Y.	40.5	+2.1	+0.9	+0.1	+0.1	-2.4	-0.6	+1.1	-1.8	+1.0	+0.7
Bismarck, N. Dak.	49.8	+1.6	+0.8	+0.4	+0.4	-2.1	-0.7	+1.0	-1.1	+0.1	+0.7
Block Island, R. I.	51.7	+0.8	+0.8	+0.6	+0.4	-2.1	-0.8	+0.3	+0.8	+0.1	+0.7
Boles, Idaho	49.5	+1.3	+0.5	+0.1	-0.0	-2.3	-0.4	+0.3	+0.8	+0.1	+0.7
Boston, Mass.	47.4	+1.0	+0.4	+0.1	+0.9	-2.5	-0.4	+0.3	+0.8	+0.1	+0.7
.....	58.2	+1.4	+0.4	-0.1	-0.8	-1.7	-0.9	+0.3	-0.8	+0.1	+0.7
.....	58.4	+1.7	+0.7	+0.1	+0.4	-1.7	-0.9	+0.3	-0.8	+0.1	+0.7
.....	52.9	+1.8	-0.9	+0.1	+0.4	-1.7	-0.9	+0.3	-0.8	+0.1	+0.7
.....	65.7	+1.1	-1.3	+0.3	+0.4	-1.7	-0.9	+0.3	-0.8	+0.1	+0.7
.....	59.9	+1.1	-1.3	+0.3	+0.4	-1.7	-0.9	+0.3	-0.8	+0.1	+0.7
n.	60.1	+0.9	+1.7	+0.2	-1.0	-1.0	-0.3	+0.6	+0.1	+1.1	+0.7
.....	44.0	+1.5	+0.7	+0.1	-1.2	+0.7	-0.2	+0.4	+0.6	+0.1	+0.7
.....	49.0	+0.2	-1.0	-0.3	-1.3	-2.4	-0.7	+0.2	-0.2	-0.7	-0.7

TABLE IV.—Temperature means (°F.) for the decade 1900–1909, etc.—Continued

	Mean	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Little Rock, Ark.....	62.0	+0.7	-0.1	-0.3	-1.4	-0.3	-1.3	-0.5	+1.0	+1.3	+1.0
Los Angeles, Cal.....	62.4	+1.1	-0.3	-1.2	-0.2	+1.5	+0.2	+0.5	+0.2	-0.5	+1.0
Louisville, Ky.....	56.9	+1.5	-0.7	-0.4	-0.5	-1.2	-0.7	+0.3	-0.4	+1.8	+0.3
Lynchburg, Va.....	56.5	+1.9	-0.8	+0.3	-0.1	-1.7	-0.4	+1.0	-0.5	+0.3	+0.4
Macon, Ga.....	63.9	+0.1	-2.0	-0.1	-1.0	-0.6	0.7	+1.0	+1.4	+1.1	+0.2
Marquette, Mich.....	41.3	+1.6	+0.4	+1.1	-0.1	-2.5	-0.7	+1.0	-2.1	+1.8	-0.1
Memphis, Tenn.....	61.6	+1.1	-0.2	-0.1	-1.0	-0.7	-1.1	-0.5	+0.8	+1.4	+0.8
Meridian, Miss.....	63.6	+0.3	-1.6	+0.3	-1.2	-0.2	-0.7	+0.2	+1.0	+1.0	+0.7
Miles City, Mont.....	46.1	+2.5	+1.8	-0.4	-0.5	-0.4	0.8	+0.7	-1.5	+0.7	-0.8
Milwaukee, Wis.....	46.6	+1.3	+0.1	+0.6	-0.6	-1.9	-0.4	+1.3	-1.1	+1.2	-0.3
Minneapolis, Minn.....	44.3	+2.0	+0.9	+0.6	-1.2	-2.1	-0.4	+0.7	-1.7	+1.9	-0.4
Mobile, Ala.....	67.2	-0.1	-1.8	0.5	-1.4	-0.4	-0.1	+0.1	+1.3	+1.2	+1.1
Montgomery, Ala.....	65.1	+0.6	-1.4	+0.5	-1.3	-0.1	-0.3	0.1	+0.8	+1.5	+0.5
Moorhead, Minn.....	40.1	+1.9	+1.4	+0.6	-1.2	-1.7	0.5	+0.7	-2.3	+1.6	-0.5
Mount Tamalpais, Cal.....	55.3	+0.2	+0.7	-1.3	+0.4	+0.8	+0.5	+0.9	-1.3	-0.2	-1.0
Nantucket, Mass.....	49.0	+1.4	-0.4	+0.2	0.2	-2.1	-0.5	+0.2	-1.1	+1.0	+0.7
Narragansett Pier, R. I.....	48.0	+1.8	-0.3	+0.7	+0.9	-2.3	-0.5	+0.9	-1.4	+1.2	+0.2
Nashville, Tenn.....	59.4	+1.0	-1.4	-0.1	-0.1	-0.8	-0.8	+0.2	+0.5	+1.4	+0.7
New Haven, Conn.....	49.7	+1.4	-0.6	+0.1	-0.1	-2.6	-0.5	+1.1	-1.0	+1.6	+0.8
New Orleans, La.....	69.2	0.	-1.0	+0.2	-1.3	+0.1	-0.5	0.	+1.2	+0.9	+0.3
New York, N. Y.....	52.4	+1.9	-0.1	+0.1	+0.1	-2.5	-0.4	+1.1	-0.6	+1.1	+0.6
Norfolk, Va.....	59.2	+1.5	-0.7	+0.1	+0.2	-1.8	-0.5	+1.0	-1.0	+0.8	+0.2
Northfield, Vt.....	40.6	+2.3	+1.0	+0.6	+0.6	-2.5	-0.6	+0.1	-1.0	+0.8	+0.3
North Platte, Nebr.....	49.5	+0.6	+0.8	-0.2	-0.6	+0.8	-0.5	+0.5	-0.8	+0.6	+0.2
Oklahoma, Okla.....	59.5	+1.6	+1.2	-0.1	-1.4	+0.3	-1.1	-1.3	-0.5	+0.4	+1.7
Omaha, Nebr.....	50.9	+1.3	+0.3	-0.5	-0.7	-1.3	-0.6	+0.2	-0.6	+1.4	+0.9
Oswego, N. Y.....	45.7	+0.3	-0.2	+0.2	+0.4	-2.6	-1.1	+1.0	-1.1	+1.2	+0.2
Palestine, Tex.....	65.9	+1.7	-0.9	+0.1	-2.1	+0.3	-1.3	-0.6	-0.8	+0.9	+1.1
Parkersburg, W. Va.....	53.9	+0.5	-1.1	+0.3	0.3	-1.6	-0.4	+0.2	+0.9	+1.2	+0.5
Pensacola, Fla.....	67.7	+1.7	-0.5	-0.1	-1.3	0.5	-0.4	-0.2	-0.9	+0.6	+0.8
Philadelphia, Pa.....	54.3	+0.9	+0.8	+0.5	-0.1	-2.5	-0.3	+1.0	-1.2	+1.2	+0.8
Phoenix, Ariz.....	69.8	+2.6	+2.2	-0.7	-1.2	+0.6	-0.7	-0.1	-0.2	-0.7	+1.0
Pierre, S. Dak.....	47.2	+2.2	+0.1	+0.7	+0.4	-0.6	-0.5	-0.3	-1.6	+1.4	-0.9
Pittsburgh, Pa.....	52.5	+1.5	+1.4	-0.4	-1.4	-1.3	-0.4	-0.3	-1.8	+0.7	-0.3
Pocatello, Idaho.....	47.8	+0.7	-0.4	+0.2	-1.4	+0.9	-0.4	-0.4	-0.3	-0.9	-0.3
Point Reyes Light, Cal.....	52.9	+1.2	0.	+0.5	-0.1	+0.3	+0.8	+0.5	+0.6	-1.2	-1.2
Port Crescent, Wash.....	46.4	+1.3	+0.2	+0.5	-0.2	+0.3	+0.5	+0.8	-0.6	-0.6	-2.2
Port Huron, Mich.....	46.0	+1.4	+0.4	+0.6	-0.1	-2.6	-0.8	+1.3	-1.0	+1.1	+0.7
Portland, Me.....	44.8	+0.3	-0.6	-0.6	+0.2	-2.7	-0.1	+0.1	-1.5	-0.3	+0.7
Portland, Ore.....	53.2	+1.4	+0.3	+0.2	-0.3	+1.1	+0.1	+1.2	+0.4	+1.2	+1.4
Pueblo, Colo.....	51.7	+0.8	-1.1	0.	-0.9	+0.2	-1.2	-0.3	+1.2	-0.5	-0.7
Raleigh, N. C.....	59.9	+1.4	+0.8	+0.9	-0.2	-1.5	-0.5	+0.9	-0.2	+0.5	+0.4
Red Bluff, Cal.....	62.3	+0.2	-0.7	-0.3	-0.8	+0.5	-0.6	+0.6	-1.1	-0.1	-0.2
Richmond, Va.....	57.9	+1.8	-0.7	+0.3	+0.1	-1.7	-0.3	+0.6	-0.9	+0.5	+0.3
Rochester, N. Y.....	47.5	+1.7	-0.4	+0.1	+0.5	-2.4	-0.5	+1.1	-1.2	+1.2	+0.2
Roseburg, Ore.....	53.2	+0.8	-0.4	0.	-0.7	+0.9	-0.1	+0.9	+0.5	-0.5	-0.9

TABLE IV.—Temperature means (°F.) for the decade 1900–1909, etc.—Continued

	Mean	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Sacramento, Cal.	59.8	+0.1	+0.3	-0.6	-0.4	+0.3	-0.1	+0.6	-0.2	-0.1	-0.1
St. Louis, Mo.	56.2	+2.1	+1.2	+0.4	-0.2	-1.8	-1.3	-0.6	-0.9	+1.2	-0.2
St. Paul, Minn.	44.5	+2.0	+1.1	+0.5	-1.0	-1.9	-0.3	+0.6	-2.0	+1.5	-0.8
Salt Lake City, Utah.	51.8	+2.0	+1.5	+0.2	-1.4	0.	-0.2	-0.7	+0.5	-1.7	-0.1
San Antonio, Tex.	69.1	+0.1	+0.6	+0.8	-2.8	+0.1	-1.3	-0.7	+1.3	+0.6	+1.2
San Diego, Cal.	61.1	+0.9	+0.1	-1.0	+0.1	+1.3	+0.3	+0.5	+0.3	-1.2	-1.1
Sandusky, Ohio.	49.8	+1.5	-0.5	+0.2	-0.2	-2.2	-0.5	+1.1	-1.2	+1.3	+0.2
San Francisco, Cal.	55.7	+0.5	-0.6	-0.3	-0.4	+0.7	+0.6	+0.5	+0.3	-0.7	-0.5
San Juan, Porto Rico.	78.3	+0.2	+0.6	0.	+0.5	-0.5	+0.1	-0.1	+0.6	+0.2	-0.5
San Luis Obispo, Cal.	58.5	+1.7	+0.6	-0.1	0.	+0.8	-0.2	+0.7	-0.3	+1.3	-1.4
Santa Fé, N. Mex.	48.9	+1.6	+1.0	+1.3	-0.2	+0.4	-1.2	-0.4	0.	-1.1	-1.2
Sault Ste. Marie, Mich.	39.7	+1.8	+0.9	+1.3	+0.5	-3.2	-0.6	+1.0	-2.8	+1.1	+0.2
Savannah, Ga.	66.5	+0.7	-1.5	+0.5	-0.7	-0.9	-0.2	-0.2	+0.6	+0.7	+0.2
Seattle, Wash.	51.7	+1.1	+0.3	+0.5	-0.5	+0.7	+0.2	+0.8	-0.6	+1.6	0.
Shreveport, La.	65.6	+0.6	-0.5	0.	-1.6	+0.3	-1.1	+0.3	-0.6	+1.0	-2.0
Sioux City, Iowa.	47.7	+1.8	+1.7	-0.2	-0.7	+0.7	-0.5	-0.3	+1.2	+1.0	+0.9
Spokane, Wash.	48.5	+1.3	+0.4	-0.6	-1.0	+1.4	-0.3	+0.9	-0.9	+1.4	-1.2
Springfield, Ill.	52.6	+1.6	+0.1	-0.4	-0.8	-2.2	-0.7	+0.6	+0.1	+0.2	-1.1
Springfield, Mo.	55.7	+1.2	+1.0	-0.8	-1.1	-0.5	-0.3	-0.8	+0.7	+1.6	0.
Tacoma, Wash.	50.8	+0.8	-0.2	+0.1	-0.8	+0.5	+0.3	+1.0	+0.1	+1.0	+0.6
Tampa, Fla.	71.6	-0.1	-1.6	-0.1	-0.6	-0.1	+0.3	-0.1	+0.9	-0.4	-1.4
Toledo, Ohio.	49.4	+1.3	-0.5	+0.2	-0.4	-2.0	-0.6	+1.0	-1.1	+0.7	+0.3
Topeka, Kans.	54.2	+1.3	+1.1	-0.8	-1.1	-1.0	-0.7	+0.3	+0.1	+1.5	+0.2
Valentine, Nebr.	46.8	+2.8	+1.4	-0.4	-0.6	+0.3	-1.4	-0.3	-0.9	+0.9	-1.9
Vicksburg, Miss.	65.5	+0.4	-0.9	+0.2	-1.4	+0.1	-1.0	-0.1	+0.9	+0.8	+0.6
Washington, D. C.	54.6	+1.9	-0.5	+0.2	-0.3	-2.4	-0.5	+1.3	-1.1	+0.8	+0.2
Wichita, Kans.	56.2	+1.2	+1.1	-0.5	-0.9	0.	-1.0	-0.7	+0.4	+1.0	-0.4
Wilmington, N. C.	62.7	+1.1	-1.3	0.	-0.1	-1.5	-0.5	+0.8	+0.1	+1.0	+0.4
Winnemucca, Nev.	48.5	+0.9	+0.1	-0.6	-1.9	+0.8	-0.3	+0.3	+1.0	-0.3	+0.2
Yuma, Ariz.	71.6	+0.5	+0.5	-0.3	+0.4	+0.8	+0.2	+0.1	-0.5	-0.6	-1.2

¹ For the Canadian Stations the annual means have been copied from the Monthly Weather Review and the figures for the American Stations have been taken from the Annual Reports of the U. S. Weather Bureau.

FIG. 22.—*Temperature departures for the year 1900*

.

23

FIG. 23.—*Temperature departures for the year 1901*

FIG. 24.—*Temperature departures for the year 1902*

FIG. 25.—*Temperature departures for the year 1903*

Leaving for the present the curves of consecutive means and the consecutive maps, which will serve later for a better comprehension of the dynamic phenomenon of the transformation of one map into another, I will describe these annual departure maps and formulate questions and suppositions, just as I did in my former research into the variations of temperature during the years 1891–1900.

The map for 1900 (Fig. 22) is peculiar in that the departures are above the average all over the States. The quasinormal line follows the Gulf of Mexico from Corpus Christi over New Orleans towards Tampa, Fla. At Key West the departure is $-0^{\circ}.5$ F. Porto Rico belongs to the pleionian area. In Bermuda the mean equals the ten-yearly mean. In the northeast there are negative departures in New Brunswick. The pleion has two centers, one in South Dakota, the other in Pennsylvania. The highest departures are $+2^{\circ}.2$ in Valentine, Neb., and $+2^{\circ}.4$ in Harrisburg, Pa. The equideparture lines of $+1^{\circ}.5$, surrounding these centers, are separated by a strip of lower departures extending from Lake Huron towards Oklahoma.²⁵

The map of 1901 shows a pleion in the west, an antipleion in the east and another pleion having its center south or southeast of Nova Scotia. In Newfoundland the departure is $+0^{\circ}.8$ C. = $+1^{\circ}.4$ F. at St. Johns. It is above $+2^{\circ}$ in Nova Scotia. The highest departures of the western pleion are $+2^{\circ}.2$ (Bismarck, N. Dak., and Pierre, S. Dak.), whereas the highest departure in 1900 was $+2^{\circ}.8$. The center of the antipleion is at Macon, where the departure is $-2^{\circ}.0$. Comparing the maps (Figs. 22 and 23), it looks as if the antipleion came from the Gulf of Mexico pushing the eastern center of the pleion of 1900 from Pennsylvania over Nova Scotia and New Foundland, while the western center remained stationary.

The map of 1902 (Fig. 24) is very different from that of 1901. The positive as well as negative departures are smaller; the contrasts between the pleions and antipleions are less accentuated than in 1901. The outlines of the areas affected by positive and negative departures are complicated. The map gives the impression of representing intercrossing waves. It is as if the western pleion of 1901 had been cut in two and as if the two centers had been moved apart: the center of South Dakota northwesterly into Manitoba and the center of Utah southeasterly towards Texas. An antipleion separates these pleions and, perpendicularly to this furrow, a ridge of positive departures extends from Louisiana to Nova Scotia. The antipleion of the west also has the shape of a wave.

²⁵ The departure of $+0^{\circ}.2$ at Chicago is evidently incorrect. The departure $-0^{\circ}.1$ of Fresno, Calif., is likewise in contradiction with the other Californian data.

4

FIG. 26.—Temperature departures for the year 1904

FIG. 27.—Temperature departures for the year 1905

FIG. 28.—*Temperature departures for the year 1906*

FIG. 29.—*Temperature departures for the year 1907*

The question is whether this antipleion, extending from Alberta to Lower California, came from the Pacific or is the southeastern antipleion of 1901 which moved across the States.

Nineteen hundred and three is a year of a predominant antipleion covering nearly the entire area of the United States and extending north and south into Canada and Mexico (Fig. 25). The most negative departures are $-2^{\circ}.4$ at Grand Junction and $-2^{\circ}.8$ at San Antonio. This antipleion has a third center in South Dakota and resembles in shape that of the preceding year. A close inspection of the maps gives the impression of a contra-clockwise movement.

If this hypothesis is justified, it must be admitted that the map of 1904 (Fig. 26) expresses the result of the continuation of this circular displacement. In 1904, the center of the antipleion is in the northeast of Lake Huron, with a departure of $-3^{\circ}.4$ at Parry Sound. In the west, on the contrary, there is now a pleion which, in this hypothesis, would also have traveled contra-clockwise, from Ontario towards Idaho.

The western pleion has two centers with $+1^{\circ}.9$ departures at Helena, Mont., and Independence, Calif. The map displays a very accentuated contrast between the temperatures in the west and in the east and is perfectly typical.

In 1905 (Fig. 27), we have again negative departures all over the States with the exception of Florida, California and parts of Washington, Montana and North Dakota. In Alberta, there is a pleion with departures as high as $+2^{\circ}.9$ (Battleford) and the same pleion extends over the Pacific, the departures along the coast being $+0^{\circ}.5$ in Port Crescent, Wash., and $+0^{\circ}.8$ in Eureka, Calif. In 1904 the departure was $+0^{\circ}.1$ in Bermuda, now it is $+0^{\circ}.6$ and it is this Atlantic pleion which extends from Bermuda over Florida towards the Gulf of Mexico. It seems that the change of the map of 1904 into that of 1905 was due to a displacement of the antipleion from northeast towards the southwest, accompanying a displacement of the pleion from the west towards the north. The movement was contrary to that of the preceding year, both the pleion and antipleion remained on the continent and traveled around in the same direction as the hands of a clock.

The year 1906 shows a continuation of this movement, at least as far as the pleion is concerned (Fig. 28).

In 1907, on the contrary, the conditions are so very different from those of 1906 that it is absolutely impossible to make any statement about the displacements which took place between these two years. The map of 1907 (Fig. 29) is precisely the reverse of that of 1906. Where there was an antipleion there is now a pleion and vice versa. The disposition

FIG. 30.—*Temperature departures for the year 1908*

FIG. 31.—*Temperature departures for the year 1909*

of the equideparture curves is the same. A seesaw movement would explain the transformation; but, as will be seen later, such an explanation is not satisfactory.

The map of 1908 (Fig. 30) indicates a simple displacement of the pleion towards the north. The shape of the pleion remained practically the same and in the west an antipleionian wave, following the movement, advanced over the continent. The pleion has two crests, one going from Alberta towards Kentucky, with the departures of $+2^{\circ}.6$ in Calgary, $+2^{\circ}.1$ in Medicine Hat, $+1^{\circ}.9$ in Bismarck, Minneapolis and Cincinnati, and a second wave following a perpendicular direction along the Atlantic coast in the New England States ($+1^{\circ}.6$ in Boston and New Haven). Curiously enough, farther south, a depression in the pleion is noticeable, the departure being $+0^{\circ}.5$ at Richmond, Raleigh and Charlotte, and only $+0^{\circ}.3$ in Lynchburg. On the Atlantic there is an antipleion, the quasinormal line going from Jupiter, Fla., towards Halifax. In Bermuda, the departure is $-0^{\circ}.9$.

Finally, the map of 1909 (Fig. 31) shows the disappearance of the northwestern crest of the pleion under the influence of the advancing antipleion, whose two distinct centers moved from Eureka towards Battleford and from Independence toward Valentine. The pleion of 1908 has been reduced to a wave extending from Nova Scotia towards Texas. The most positive departures are $+1^{\circ}.1$ in Sydney, Grand Manan and Charlottetown, and $+1^{\circ}.7$ in Fort Worth, Tex.

To gain a more precise knowledge of the displacements of the pleions and antipleions, which took place during the years 1900–1909, I made consecutive maps and consecutive curves. I will examine separately the results gained by the study of the curves and of the maps.

CONSECUTIVE MAPS

The annual departures of 175 stations were utilized to draw the maps I have just described. To obtain similar consecutive maps would have involved a great amount of purely clerical work. I simplified the task by omitting the Canadian data and taking only the means of the twenty-one districts into which the United States are divided in the columns of data published in the "Monthly Weather Review." I copied the monthly means for the years 1900–1909 for these districts, then calculated the consecutive totals, then the individual means and finally the departures of these means from the normal values. This last operation was somewhat arbitrary and I would certainly have done better by taking the departures from the ten-yearly means.

At the beginning, I had no intention of doing the work for all the years and so I made the annual departures correspond to those given in the "Monthly Weather Review." These departures are probably taken from the means of the entire series of observations, and these means increasing or decreasing as the number of years taken into consideration increases, the departures are necessarily not homogeneous. This lack of homogeneity has no importance, since I adjusted the values, for each year, so they would correspond to the last annual departures (from the normals) given in the annual summaries of the "Monthly Weather Review."

The material which I have at hand consists of ten annual maps, giving the distribution of the annual departures from normal means, and of one hundred eight consecutive maps, showing the progressive changes of the map of each year into that of the following year.

First of all, I must say that comparing the ten annual maps, obtained by utilizing district departures, with the ten detailed maps, described previously, one has to admit that the method of grouping the results of different stations to obtain regional averages is most inconsistent and defective. One can imagine how inefficient our daily weather maps would be if instead of utilizing the values given for individual stations we made regional averages. Still, even such smoothed weather maps would give some idea about the position of lows, and highs and cold waves could also be located, though in a very vague and unsatisfactory way.

On the consecutive maps I have drawn, the pleions and antipleions are of course badly deformed and most interesting details are lacking, but the more or less progressive displacements taking place can easily be followed and the precise moments when the important changes in the distribution of temperature occur are detected without great difficulty. I will therefore compare the maps, simply in order to reach a better understanding of the transformations of the annual departure maps from one to another.

1900-1901. The consecutive maps show that the antipleion of 1901 came from the south and progressed westward over the States. After some minor oscillations of the quasinormal line,²⁶ the upward movement of the antipleion starts with the map of September, 1900,-August, 1901. The annexed diagram shows the successive positions of this line on the consecutive maps for the periods ending in August, September, October, November and December, 1901 (Fig. 32). The western pleion remained practically unchanged.

²⁶ These quasinormal lines deal with departures from normal values, and, evidently, differ from those of the maps expressing the distribution of departures from ten yearly means.

1901-1902. The western antipleion of 1902 is not the southeastern antipleion of 1901. The consecutive maps show that the center of the antipleion remained nearly stationary over the Atlantic, east of Georgia or South Carolina, and that, at the end of the year, the negative area extending over the States moved eastward.

The following diagram (Fig. 33) shows the successive positions of the quasinormal line for the consecutive maps of November, 1901,-October, 1902, until January-December, 1902. The maps show an interesting feature concerning this antipleion. Its disappearance from the map was preceded by a progressive shrinkage followed by an expansion. The shrinkage began with April, 1901,-March, 1902, and continued until June, 1901,-May, 1902, when the quasinormal line lay from Washington over Louisville and Memphis towards Vicksburg; then, the negative area

FIG. 32.—*Successive positions of the quasinormal line*

FIG. 33.—*Progressive displacements of the antipleion of 1901*

increased again progressively until November, 1901,-October, 1902, and was followed by the eastward movement shown on the diagram.

The consecutive maps do not give a satisfactory account of the formation of the negative wave which, on the map of 1902, extends between the pleions of Canada and Mexico. The regional departure maps do not show the existence of the two pleionian centers of 1901 (Fig. 23) until towards the end of the year. The movement of separation begins with December, 1901,-November, 1902, and corresponds to the rapid drift of the eastern antipleion towards the southeast. The western antipleion of 1902 (Fig. 24) came from the southwest and spread out, progressively, over the entire area of the United States.

1902-1903. Evidently the quasinormal line of the consecutive maps is not the same as the quasinormal line of the departure maps from the means of the decade 1900-1909, but the displacements shown and the transformation of the consecutive maps must be similar to those of the detailed yearly maps. I repeat this statement to avoid misunderstanding.

On the consecutive map of 1902, the western antipleion is very much less developed than on the departure map of 1902 (Fig. 24). This is evidently due to the fact that the normals adopted in the "Monthly Weather Review" are very different from the means of 1900-1909.

The following diagram (Fig. 34) gives the successive positions of the quasinormal line on the maps ending with October, 1902, December, 1902, February, 1903, May, 1903, and August, 1903. Figures 35-37 are the consecutive maps for the years ending with September, October and No-

FIG. 34.—Displacements of the quasi-normal line

FIG. 36.—Departures of temperature averages for November, 1902,—October, 1903

FIG. 35.—Departures of temperature averages for October, 1902,—September, 1903

FIG. 37.—Departures of temperature averages for December, 1902,—November, 1903

vember, 1903. These diagrams show plainly that we do not have to deal with a simple displacement from west to east or southwest to northeast.

We see that the pleion and antipleion are not only dependent upon each other for their displacements but also have a tendency to remain on the continent. The antipleion moving eastward displaces the pleion, first northward then northwestward and finally westward. The pleion and antipleion move *en bloc* contra-clockwise.

1903-1904. The map of 1904, without a doubt, expresses the continuation of this dynamic phenomenon. The change, however, in the respective positions of the two centers is not progressive. The following four maps (Figs. 38-41) show indeed that for February, 1903,-January, 1904, the temperature conditions were still very similar to those of 1903, whereas for April, 1903,-March, 1904, the distribution of the negative departures already had the character of the map of 1904. The development of the western pleion was delayed, and it is only on the consecutive map ending in November that its maximum development is reached.

FIG. 38. — *Departures of temperature averages for February, 1903,-January, 1904*

FIG. 40. — *Departures of temperature averages for April, 1903,-March, 1904*

FIG. 39. — *Departures of temperature averages for March, 1903,-February, 1904*

FIG. 41. — *Departures of temperature averages for May, 1903,-April, 1904*

1904-1905. The consecutive maps showing the transformation of the temperature conditions of 1904 into those of 1905 are most interesting, because they show a slow and continuous movement. The pleion and antipleon remain bound together and both remain on the continent; but the displacement is reversed and now it goes clockwise. The following two diagrams (Figs. 42-43) will be sufficient to demonstrate intermediate stages between 1904 and 1905. The first one is of the twelve-

monthly means ending with February, 1905, and the second gives the distribution of the departures of July, 1904,—June, 1905.

1905–1906. The map of 1905 (Figs. 27 and 44) shows a large pleion in Canada, another on the West Indies and Florida, and an extensive antipleion with two centers, one in Texas and the other on Nova Scotia. The consecutive map of February, 1905,—January, 1906 (Fig. 45), shows the two pleions joined together, separating the two antipleionian centers.

The following maps show the shifting and final disappearance of the northeastern antipleion, but the southern or southwestern antipleion remains, undergoing small changes of position or extent.

FIG. 42.—*Departures of temperature averages for March, 1904,—February, 1905*

FIG. 44.—*Departures of temperature averages for January–December, 1905*

FIG. 43.—*Departures of temperature averages for July, 1904,—June, 1905*

FIG. 45.—*Departures of temperature averages for February, 1905,—January, 1906*

The variation of the departures is of some interest. The highest departure in the north is $+1^{\circ}.1$, for 1905, in the North Dakota district $+2^{\circ}.1$, for February, 1905,—January, 1906, $+2^{\circ}.3$ for March, 1905,—February, 1906, and then decreases to $+1^{\circ}.0$ and afterwards increases again progressively until November, 1905,—October, 1906, when it reaches $+2^{\circ}.5$. At the center of the antipleion, the negative departures for the first three consecutive maps are $-1^{\circ}.4$, $-1^{\circ}.1$ and $-0^{\circ}.8$. A general

increase of temperature takes place all over the States, in the pleionian as well as in the antipleionian area. Then, towards the end of the year, the negativity of the antipleion increases with the increase in positivity of the pleion.

The contrast between the positive and negative departures decreased and then increased. This particular case shows therefore very well the importance of minor oscillations, taking place independently of the displacement of pleions and which, at the same time, may interest larger areas than those covered by pleions and antipleions. I reproduce only

FIG. 46. — *Departures of temperature averages for January–December, 1906*

FIG. 48. — *Departures of temperature averages for April, 1906,–March, 1907*

FIG. 47. — *Departures of temperature averages for February, 1906,–January, 1907*

FIG. 49. — *Departures of temperature averages for June, 1906,–May, 1907*

the first two consecutive maps showing the junction of the two pleions (Figs. 44, 45). The other maps simply illustrate a progressive disappearance of the southeastern center and the minor oscillations of the southern antipleion.

1906–1907. The maps of 1906 and 1907 (Figs. 28, 29), by their precisely opposite character, seem to indicate a simple seesaw oscillation in the distribution of temperature.

The consecutive maps contradict this supposition. The following dia-

grams, representing the conditions for 1906, February, 1906,–January, 1907, April, 1906,–March, 1907, and June, 1906,–May, 1907 (Figs. 46–49), show that the transformation began with a slight rotary movement, followed by a displacement of the pleionian center from the north towards the south, and then by a displacement of the pleion towards the west and of the antipleion towards the east.

1907–1908. The pleion of 1908 (Fig. 30) is so similar to that of 1907 that one would think that nothing extraordinary happened during the year and that there was simply a shifting of the pleion towards the northeast. In reality, the consecutive maps show that the pleion and antipleion moved first around, with the hands of a clock, so that for February, 1907,–January, 1908, the quasinormal line had already extended from North Dakota towards Tennessee and Virginia, as is shown on the following diagram (Fig. 50), then the antipleion extended farther south (April, 1907,–March, 1908), and from then on it was driven away

progressively in a northeasterly direction. The lines of the diagram show the successive positions of the quasinormal line. The 1908 western antipleion is, in June, 1907,–May, 1908, already on the plateaux and from then on its negativity increases progressively.

FIG. 50.—Displacements of the quasinormal line on the consecutive departure maps of February, 1907,–January, 1908, till July, 1907,–June, 1908

1908–1909. Finally, the last twelve consecutive maps show that the axis of the pleion of 1908 first turned slightly to a north-

south direction, then moved eastward, then back again to the west. For November, 1908,–October, 1909, there were two pleionian centers, one in North Dakota, the other in Texas. The advance of the antipleion towards the northeast is seen only on the last consecutive map.

So far, the consecutive maps have served only to explain the transformation of the departure map of one year into that of the following year. One might be satisfied with the results obtained, the consecutive maps having served their purpose in a satisfactory way.

The principal conclusion gained is that the method used could be applied to seasonal forecasting; but it is evident that, for such a purpose, it would be necessary to draw the consecutive maps as correctly as possible, by calculating the means for all the individual stations.

It is also evident that the same would have to be done for the rainfall

data, the atmospheric pressure and the velocities and directions of the observed winds.

In the present state of our knowledge of the phenomena governing the climatical variations, however, it would be most unscientific to try to make seasonal forecastings, since, at present, we see only the possibility of arriving at practical results by pursuing patiently the research work in a well-established direction. With the immense amount of work which yet remains to be done before a clear understanding of the climatical variations will be reached, any test of the method employed, in order to show its practical value, would be completely out of place.

To show how each step forward leads to new questions to be solved and new research work, having apparently nothing in common with the pursued purpose, I will note a few problems arising from a closer examination of the consecutive maps.

First of all, during the years 1900–1909, the pleions as well as the antipleions displayed a tendency of persistence. No seesaw movement, between a pleion and an antipleion, leading to the gradual disappearance of both and then to the formation *in situ* of a pleion on the place formerly occupied by the antipleion and vice versa, could be traced. Minor seesaw oscillations took place, but they served simply to increase or decrease the contrast between the pleions and antipleions without destroying them. Together with a tendency to persist goes a tendency of displacement. These displacements are generally gradual and continuous, but sometimes they may be very rapid and in striking contrast to the nearly stationary conditions which preceded or followed the rapid change of position. The problem is, then, to know what makes a pleion remain on the map during several years and what makes the pleion move from one region to another.

Another fact is the tendency of the pleions and antipleions to remain on the continent. In other words, the phenomenon of the variation in the distribution of the anomalies of yearly temperatures in North America is to a great extent a purely North American phenomenon.

This leads naturally to another question of some importance. The pleions and antipleions seem to be correlated or bound together. One depends on the other, and if one moves the other moves. The area of the North American continent seems not to be wide enough for the simultaneous presence of many pleions and antipleions. In order to remain on the continent, the motion of a pleion involves a displacement of the antipleion in an opposite direction. A rotary movement is the consequence. It is a pendulation.

The following diagram shows in a schematic way the pendulations of

the pleionian center (Fig. 51) and expresses simply the tendency of the displacements, during the years 1900-1909, and may serve as an illustration facilitating the comprehension of the problem. For precision it would have been necessary to have detailed consecutive maps.

The principal problem is of course, what keeps the pendulation going? Without some exterior impulse, the movement would die out or could not even originate. It seems to me highly improbable that a mechanical working as is exhibited on the diagram could be due to variations of the Atlantic ice conditions. Without doubt, it is the cause of the for-

FIG. 51.—*Pleionian pendulations*

mation of pleions which, repeating itself more or less periodically, gives the impulse to the clockwork.

The Russian pleions have shown some correlations with the equatorial variation of temperature, illustrated by the consecutive curve of Arequipa. The consecutive curve of New York also belongs to the Arequipa type. We see now how the tendency of the pleions to maintain their existence complicates the problem of their mode of formation or origin.

The following diagram (Fig. 52), which expresses graphically the last

FIG. 52.—*Pleionian amplitudes and the Arequipa curve*

problem I have to mention in connection with the study of consecutive maps, shows plainly that, independently of the pendulations, the Are-

quipa variation affects the entire system of North American pleions and antipleions.

I have taken the differences between the highest and lowest departures for each map, in other words, the total amplitude between pleions and antipleions. The curve is reversed and I have drawn the Arequipa curve underneath to make the comparison easier. From 1900 until 1906 these two curves are similar. Between 1906 and 1907 an interesting anomaly is noticed. The Arequipa temperatures decreased from 1900 to 1909. In the United States, the differences between pleions and antipleions were also decreasing during that period of years.

CONSECUTIVE TEMPERATURE CURVES FOR SEVERAL STATIONS IN THE UNITED STATES

In order to simplify the work, it was necessary to take into consideration the consecutive means of district data, and it is evident that the overlapping maps obtained from these figures are but a first approximation. I will now complicate the problem anew by showing how the passing pleions and antipleions affected the succession of means observed at individual stations.

TABLE V.—*Extreme values of consecutive means*

	Highest	Lowest	Difference	
			°F.	°C.
Key West.....	77.6	74.3	3.3	1.8
Tampa.....	73.0	69.6	3.4	1.9
Savannah.....	68.1	64.7	3.4	1.9
Raleigh.....	61.8	58.0	3.8	2.1
Washington.....	56.6	52.1	4.5	2.5
New York.....	55.9	50.2	5.7	3.2
Portland.....	46.7	42.1	4.6	2.6
Eastport.....	43.6	38.9	4.7	2.6
Sault Ste. Marie.....	42.1	36.3	5.8	3.2
Duluth.....	41.5	35.0	6.5	3.6
Havre.....	44.9	37.6	7.3	4.1
Miles City.....	48.6	43.5	5.1	2.8
North Platte.....	51.8	47.9	3.9	2.2
Wichita.....	57.9	54.4	3.5	1.9
Shreveport.....	67.6	63.8	3.8	2.1
New Orleans.....	71.6	67.7	3.9	2.2
Eureka.....	53.7	50.4	3.3	1.8
Los Angeles.....	64.6	61.0	3.6	2.0
El Paso.....	65.1	62.2	2.9	1.6
Corpus Christi.....	72.4	69.0	3.4	1.9
Arequipa.....	58.8	56.3	2.5	1.4

Not taking into account, at present, the actual monthly means, I will examine the consecutive annual means, or rather the curves expressing graphically the variations of these figures.

The stations for which I made the necessary calculations are Eastport, Portland, Me., New York, Washington, Raleigh, Savannah, Tampa, Key

West, Sault St. Marie, Duluth, Havre, Miles City, North Platte, Wichita, Shreveport, New Orleans, Eureka, Los Angeles, El Paso and Corpus Christi. In figures 53-56, I reproduce the diagrams obtained and in

FIG. 53.—*Consecutive temperature curves of Atlantic coast stations*

Table V, I give the values of the highest and lowest consecutive means and their differences in °F. and °C.

The curves of the stations along the Atlantic coast have already been published in my paper on the climatical changes recorded in New York City. In that paper I said:

"The Arequipa curve descends; all the others, on the contrary, are ascending curves (Fig. 53). This contrast leads to the conclusion that the pleionian crests are independent of the long-range variations. Annual departures from ten-yearly means may therefore lead to very erroneous conclusions. At Arequipa, for example, the annual means for 1901 and 1902 are higher than the average of the decade taken into consideration; they form positive departures, although belonging to a depression of the curve.

"This is a strong argument against using such departures without considering at the same time the trend of the curves. Now, the Arequipa curve has four crests and four depressions. So has the curve of New York. The most important difference between the two curves is that the maxima and minima of the curve of New York occur a few months later than those of Arequipa. One may say about three months later.

"All the other curves are identical with the curve of New York in some particulars. For example, the depression of 1904 appears on all the curves. It occurs sooner in Tampa and Savannah than in Raleigh, Washington and New York. In Portland, and even more so in Eastport, this depression is very much retarded. The first crest in the Eastport curve, furthermore, reappears, although greatly diminished, in the first depression of New York, which later corresponds to that of Arequipa. One can follow the gradual attenuation of this feature going south. For 1902 we have a positive departure in Eastport belonging to a pleion. This pleion (1901-1902) has evidently nothing in common with the equatorial variation of Arequipa and the other tropical stations. It is another wave having another origin and whose occurrence is marked all along the Atlantic coast in the midst of the anti-pleionian deficiency of temperature. About 1905 the curves of the southern stations differ greatly from the Arequipa curve. The curves of the northern stations, on the contrary, are similar to the curves of Arequipa and New York, except at the end. In Eastport we indeed notice a crest between 1909 and 1910 which is not a retarded crest, and going south, we observe the same attenuation of this phenomenon as between 1901 and 1902."

I will compare the other curves in a similar way.

In the following diagram (Fig. 54), I reproduce the curves of Miles City, Duluth, Sault St. Marie and Eastport. These curves are very much alike. The only striking difference is that the variation of Miles City is more or less in advance of the others.

The curves of Fig. 55 are those of the line of stations between Havre, Mont., and New Orleans. The variation of New Orleans is to a certain extent opposite to that of Havre, and so it is most interesting to compare the diagrams one by one and see how the features of one curve gradually disappear in favor of those of other curves. The curve of Wichita, in particular, has a most unsettled appearance, since it participates in the

variations of the northern plateaux as well as of those of the Gulf. A certain similarity with the curve of Aachen (Fig. 11) is undeniable. Some other localities of the middle states would give perhaps even a better example of an unsettled variation.

Figure 56, on which the consecutive curves of Eureka, Los Angeles, El Paso and Corpus Christi are reproduced, shows that on the Pacific, as

FIG. 54.—*Temperature variation of Montana (Miles City) compared with that of Maine (Eastport)*

well as on the Atlantic, the pleionian variations are very pronounced, presenting a striking difference with northwestern Europe. Moreover, the curve of Eureka is similar to the Arequipa curve, and even shows exceedingly interesting small details of the Arequipa curve, details which cannot be ascribed to chance circumstances. It is also worthy of note that the Eureka variation is in advance of that of Arequipa. The pleionian crest of 1904-1905 is evidently out of the question. This pleion appears

ANNALS

even sooner in Los Angeles, where it corresponds in time to the principal antipleion of the curves of New York and Arequipa; but brachypleionian particularities, such as the V-shaped depression of March, 1909,—Febru-

FIG. 55.—Temperature variations in Montana, Nebraska, Kansas and Louisiana

ary, 1910, appear later in Arequipa than in Eureka. The El Paso curve shows a variation opposite to that of Arequipa and retarded. The Corpus Christi curve is more complicated, opposition and similarity of variation being combined.

We may say, therefore, that the consecutive curves of temperature for the United States, if compared with the Arequipa curve, may belong to a direct type similar to the Arequipa variation (considered as a standard of the equatorial or direct variation), or to an inverse type." Some curves, it may be added, must be called indifferent, since, to a certain extent, they belong to both types of variation at the same time. Finally, there is the independent type.

FIG. 56.—Comparison of variations in California and Texas with the Arequipa curve

Most curves may belong, temporarily, to one type or the other, but this is not a complication, because, if the results gained from the comparison of the consecutive maps are kept in mind, it is plain that it could not be

"Compare the maps published by FRANK H. BLOOM "Studies on the circulation of the atmospheres. . . ." Monthly Weather Review, Vol. 31, p. 515. Washington, 1903. Also: SIR NORMAN LOCKYER and WM. J. S. LOCKYER: "The behaviour of the short-period atmospheric pressure variation over the earth's surface." (Proc. Roy. Soc. London, Vol. 73, p. 457. London, 1904.)

otherwise. Since the pleions displace themselves, the crests of the curves cannot occur simultaneously everywhere, and since it has not been possible to detect important and persistent seesaw centers, it seems *a priori* very improbable that the direct and inverse types of variation could be characteristic for certain given locations. Therefore, there is no fixed location for the inverse or compensating type.

An inspection of the consecutive curves shows, however, that in New Mexico, Arizona and Southern California the existence of a center, where the variation displays a striking preference to belong to the inverse type, may be suspected, and that, on the contrary, in Pennsylvania and Oregon, the direct type must be predominant.

Are these locations centers of origin of pleionian variations? Not necessarily. Besides, the records of only ten years of observations are insufficient to give definite results. Even such as it is, the result gained leads to further investigations in regard to the question of the mode of formation of pleions *in situ*.

Leaving this question as an unsolved problem, I will pass to another most puzzling subject.

Since, for certain parts of the United States, the consecutive temperature curves belong to the direct type,—that is to say, are similar and coincide more or less in time with the equatorial curves,—the impulse producing these variations must be the same as that which produces the tropical variations. This impulse is evidently extra-terrestrial. Therefore, where the variation is direct, the departures of temperature will not be due to abnormal conditions of atmospheric circulation but will, on the contrary, produce such changes of atmospheric pressure, wind direction and velocity, etc., as may be characteristic for pleions or antipleions. On the maps the pleions do not disappear: they move away.

Now the question is how—in a direct type of variation—the pleion corresponding to the second crest of the consecutive curve is renewed. Is it the same pleion coming back from the region it was pushed away from by the formation *in situ* of the direct antipleion, or is it a new pleion, and if so what became of the first one?

Let us call the pleionian crests of the Arequipa curve A, B, C and D (Fig. 1). The consecutive maps show that the crest B of New York went northwest over Canada and then southwest towards California. The pleion came back nearly the same way during 1904–1906. The crest C of New York is therefore the same as B; but, if we try to follow this pendulation on the consecutive curves of individual stations, we do not succeed very well. This is because, as has been shown in Fig. 52, the amplitude of the departures changes independently of the pendulation.

The pleions pendulate and surge at the same time. An old pleion may be reintensified. In the case of the pleions B and C the surging is nothing but the superposition of a new pleion upon an old one, so that C is the residual of B, plus a new impulse produced *in situ* under the influence of the direct solar action. In this way, it is conceivable why the pleionian variations may be more important on the North American continent than the identical variations in tropical regions.

ABOUT TEMPERATURE VARIATIONS AND THE CHANGES OF THE ARCTIC ICE CONDITIONS

In order to connect the European annual departure maps with those of the North American continent, I utilized the results of the observations made at St. Johns, N. F., Upernivik, Jacobshavn and Ivigtut, on the west coast, and Angmagsalik, on the east coast of Greenland, those of the Icelandic stations Stykkisholm, Vestmannö, Grimsey and Berufjord and, finally, the observations made in Thorshavn of the Faroë Islands. For information about the variations which occurred on the Atlantic Ocean, I took the results of the observations made in San Juan (Porto Rico), Hamilton (Bermuda), Angra do Heroismo and Ponta Delgada (Azores), Funchal (Madeira), St. Vincente de Cabo Verde and, finally, those of St. Helena.

The St. Helena observations were extracted from a report of J. S. Dines.²⁸ The portuguese data were kindly sent to me by the Director of the Observatory of Lisboa, in manuscript for the years 1906–1909 and in printed form for the previous years.²⁹ The data for Bermuda were copied from the "Monthly Weather Review" and the reports of the Meteorological Service of Canada. Those for Porto Rico were sent to me by Section Director Oliver L. Fassig. The results of the observations made at Danish stations were sent to me by the Director of the Meteorological Institute of Copenhagen.³⁰ Finally, the data for Newfoundland were copied from the Canadian Reports. Unfortunately, for the period of years taken into consideration, only the records of St. Johns are complete.

It would have been very desirable to have some records for Labrador and the Hudson Bay region, to obtain a closer connection between Greenland and Canada, but the distances between Ivigtut and St. Johns, Father Point and Quebec are so much smaller than the ordinary pleionian dimen-

²⁸ JOHN SOMERS DINES: Climatological tables for St. Helena, with a report on . . . (Meteor. Office Publ. No. 203: The trade winds of the Atlantic Ocean, London, 1910.)

²⁹ Anaes do Observatorio do Infanta d. Luis. Obsarvacoes dos postos meteorologicos.

³⁰ Meteorologisk Aarbog . . . Anden del: Faerøerne, Island, Grönland og St. Croix. Udgivet af det danske meteorologiske Institut.

sions, that it is perfectly safe to say that the records of Greenland and Iceland are entirely sufficient for the purpose of the questions I had to solve.

In Table VI, I give the annual departures from the ten-yearly means of temperature for the stations now taken into consideration, the dia-

FIG. 57.—Temperature variations in Greenland, Iceland and Faroe

grams (Figs. 57–60) express graphically the succession of consecutive means, and in Table VII, I give the highest and lowest of these values as well as their differences.

TABLE VI.—Temperature data for Iceland, Greenland and the Atlantic Islands

	°C.	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909
Thorshavn	6.5	+0.2	+0.4	-0.2	-0.2	+0.3	+0.2	-0.5	-0.5	+0.3	-0.4
Vestmannö	5.4	-0.1	0.	+0.1	-0.3	+0.1	+0.1	-0.5	-0.4	+0.4	+0.2
Stikkisholm	3.2	+0.3	+0.7	-0.5	-0.7	-0.1	+0.3	-0.3	-0.7	+1.0	+0.4
Grimsey	1.8	+0.4	+0.5	-1.4	-0.7	+0.4	+0.1	-0.5	-0.8	+1.2	+0.5
Berufjord	3.4	+0.1	+0.6	-0.8	-0.3	+0.5	+0.3	-0.5	-0.8	+0.5	+0.2
Angmagsalik	-2.1	+0.7	+1.0	-0.5	+0.3	-0.6	-0.5	-0.6	-0.3	+0.9	+0.3
Upernivik	-8.2	..	+0.2	+0.5	+0.1	-1.0	+0.6	-0.7	-1.2	+0.8	+0.1
Jacobshavn	-5.0	+1.0	+0.5	+0.2	+0.3	-0.5	+0.8	-1.4	-1.3	+0.1	-0.1
Ivigtut	+0.6	+0.5	+0.9	+0.3	-0.8	-0.4	+0.2	-1.1	-1.0	-0.3	+1.1
St. Johns	4.9	0.	+0.8	+0.5	+0.1	-0.6	-0.8	+0.3	-1.4	+0.8	+0.9
Funchal	18.0	+0.5	+0.2	+0.4	+0.1	-0.1	0.	+0.2	-0.4	-0.3	-0.1
St. Vicente	23.6	+0.8	+0.5	+0.3	0.	-0.2	0.	0.	-0.7	-0.5	0.
Angra	17.3	+0.4	+0.2	-0.3	-0.3	-0.7	0.	0.	+0.7	+0.1	+0.3
Ponta Delgada	17.4	+0.4	+0.2	-0.4	-0.4	-0.6	0.	0.	+0.8	+0.2	-0.2

TABLE VII.—Extreme values of consecutive means

	Highest	Lowest	Difference °F.	Difference °C.
San Juan, Porto Rico	78.9 F.	77.5 F.	1.4	0.8
Hamilton, Bermuda	70.2 F.	69.2 F.	1.0	0.6
St. Johns, N. F.	43.1 F.	38.7 F.	4.4	2.4
Ivigtut, W. Greenland	+1.8 C.	-0.9 C.	..	2.7
Jacobshavn, W. Greenland	-3.6	-7.0	..	3.4
Upernivik, W. Greenland	-6.8	-9.8	..	3.0
Angmagsalik, E. Greenland	-0.7	-3.4	..	2.7
Berufjord, Iceland	4.5	-2.1	..	2.4
Grimsey, Iceland	3.3	-0.2	..	3.5
Stikkisholm, Iceland	4.5	2.1	..	2.4
Vestmannö, Iceland	6.3	4.7	..	1.6
Thorshavn, Faroe	7.1	5.8	..	1.3
Angra do Heroismo, Azores	18.1	16.5	..	1.6
Ponta Delgada, Azores	18.2	16.8	..	1.4
Funchal, Madeira	18.7	17.4	..	1.3
S. Vicente de Cabo Verde	24.1	22.9	..	1.2
St. Helena	62.5 F.	59.0 F.	3.5	1.9

The following questions may be taken into consideration:

- 1). Is there any trace of the Arequipa variation on the consecutive curves of Arctic stations?
- 2). How far do the pleionian variations of the North American continent extend over oceanic areas?
- 3). Is there a system of Atlantic variations independent of those of Europe and North America?
- 4). What are the connections between the continental variations and those observed in the Arctic regions?
- 5). Do the Arctic ice conditions influence the variations of annual temperatures observed on continental areas?

FIG. 58.—*Temperature variations in Newfoundland and Maine*

The curves on Fig. 57 give an answer to the first of these questions. Two types are distinguishable: the west Greenland type, best represented by the curve of Jacobshavn, and the Icelandic, or let us say Grimsey type. Angmagsalik, on the east coast of Greenland, belongs to the Icelandic type and the curve of Ivigtut is transitional, since it is similar to the curve of Jacobshavn until 1905 and very much more like the curve of Angmagsalik after 1905 or 1906.

If we compare the curves of Jacobshavn and Grimsey with the Arequipa curve we must admit some similarities which are too well pronounced to be ascribed to a simple chance circumstance. With the exception of the part comprising the consecutive means of February, 1903,—

January, 1904, to October, 1904,—September, 1905, the Grimsey curve shows all the crests and depressions of the Arequipa curve slightly retarded. Jacobshavn, on the contrary, is in advance of Arequipa.

Grimsey is a small island situated on the Polar Circle, north of Iceland, and the latitude of Jacobshavn is $69^{\circ} 13' N$. Both of these stations, therefore, are under the influence of polar currents and polar ice.

If the consecutive temperature curves of these stations display similarities with the Arequipa curve, and, in consequence also with those of Bulawayo and Mauritius, we must admit that it is absolutely out of the question to search for an explanation of these variations in the changes of polar ice conditions.

The second question could not be answered by a simple inspection of

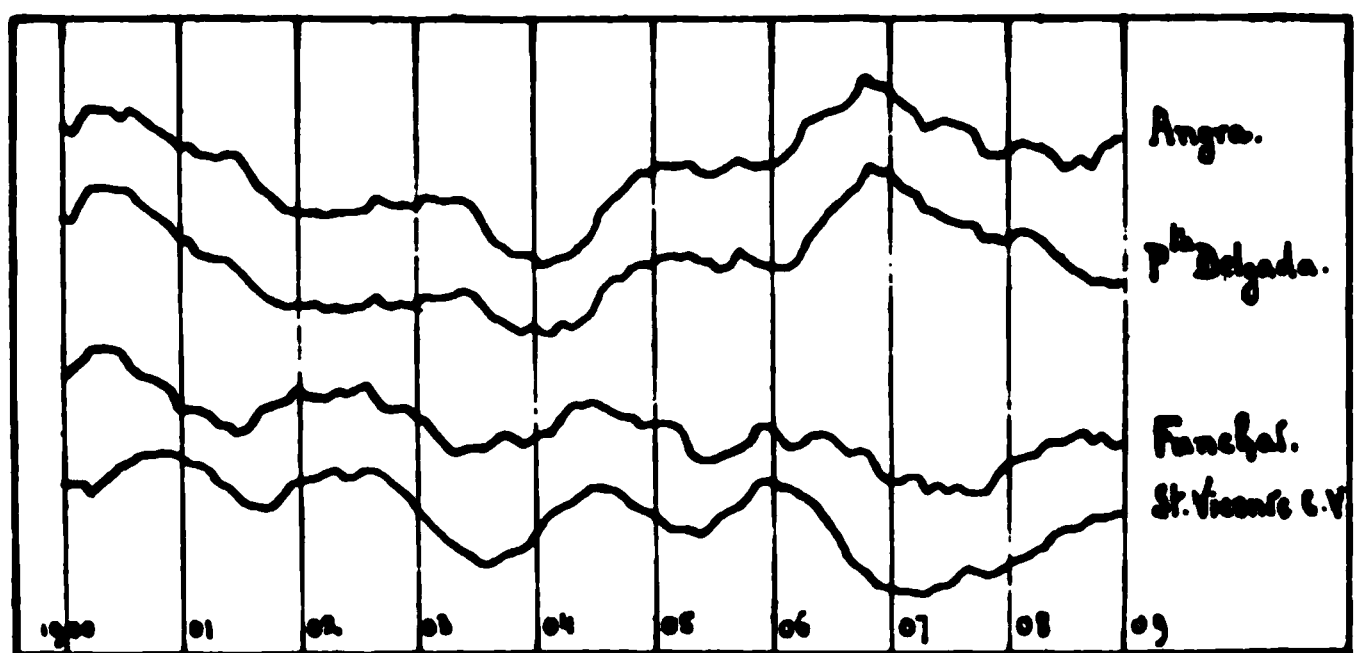


FIG. 59.—Temperature variations in the Azores, Madeira and Cape Verde Isl.

the departures given in Table VI and the curves of consecutive means of Figs. 59 and 60. Therefore, I have drawn maps showing the probable connections between the European and American pleions. The map for 1909, which I reproduce here (Fig. 61), may serve as an example.

On this map there is a continuous chain of pleionian centers extending from northeastern Russia over Greenland and Labrador towards Texas and probably Mexico. The quasinormal line goes between Iceland and the Faroes, the departures being $+0^{\circ}.2$ in Berufjord and Vestmannö and $-0^{\circ}.4 C.$ in Thorshavn. In the latitude of Newfoundland, the quasinormal line must go between the continents and run in a southern direction towards the Azores, where Angra do Heroismo belongs to the American pleions and Ponta Delgada to the western European antipleion.

The other maps also show, in a convincing way, that there can be no question of a special Atlantic variation. Parts of the Atlantic area belong to one pleion or the other or are covered by an antipleion separating pleions.

The fourth question, "What are the connections between the continental variations and those observed in the Arctic regions?" can best be answered—with the maps on hand—by saying that the north polar annual temperature changes form, probably, an intrinsic part of those occurring in Europe, Siberia and North America. The ice-covered Arctic Ocean connects Nowaya Zembla and the Siberian shores with Arctic America into one immense continental area. On this area, pleions and antipleions are formed and conjugate into one system.

The question, "Do the Arctic ice conditions influence the annual temperatures observed in Europe and North America?" ought therefore be reversed into the question, "How do the pleionian—or let us say the

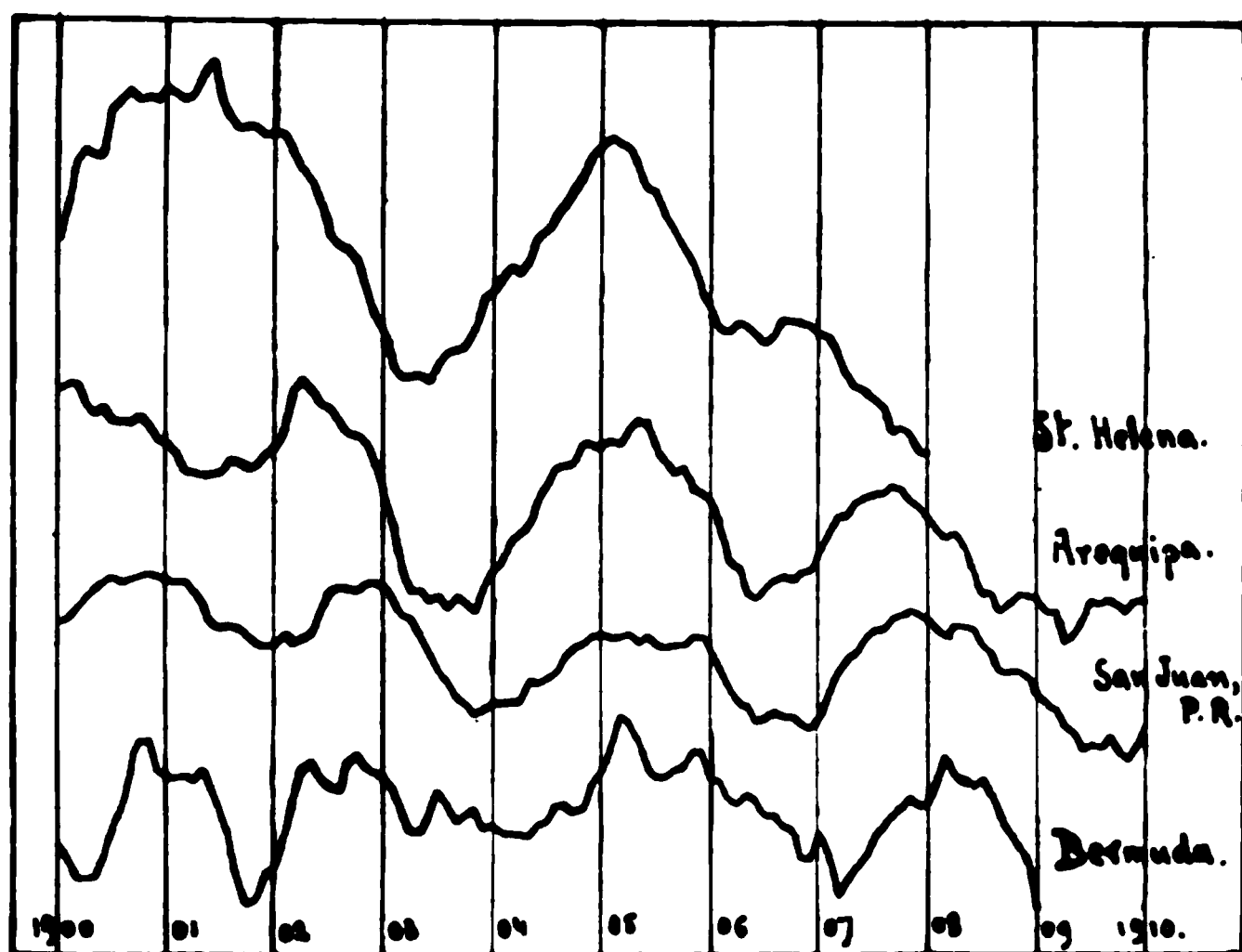


FIG. 60.—Temperature curves at St. Helena, Arequipa, Porto Rico and Bermuda

Arequipa variations—influence the ice conditions?" This is a very wide subject, about which much might be said.

Air temperature is only one of the factors influencing the drift of polar ice. Ocean currents, and especially the winds, are more important factors than temperature. It is very well known that in the Arctic, as well as in the Antarctic, the ice conditions of certain regions may vary considerably one year from another and, from the knowledge gained in the North American archipelago—the Northwest Passage in particular—we must infer the existence of long-range or even secular variations.

The quantity of icebergs drifting down into the path of the transatlantic ocean steamers also varies considerably. The same may be said about the Antarctic.

Speaking of ice conditions we must make a distinction between icebergs and sea ice, the conditions under which these two kinds of ice are produced and drift being absolutely different.

Icebergs are anchored deep in the water and are much less influenced by the direction of the winds than by the ocean currents. They originate at the glaciers. The quantity of icebergs carried down through Davis Strait, for example, and along the Newfoundland Banks, will depend mostly on the factors which acted upon the flow of the glaciers. Supposing normal conditions of the glaciers (for example, a regular advance), a succession of cold years followed by a warm year and, in particular, an abnormally warm summer, will favor considerably the production of icebergs.

In 1909, for example, much ice was noticed in the Atlantic.³¹

The consecutive temperature curves of Upernivik and Jacobshavn give an explanation to this fact. During 1906 and 1907 we notice a remarkable depression in the curves (Fig. 57), followed by a steep ascent, culminating, in 1908 and 1909, farther south, in Ivigtut.

The drift of polar sea ice, on the other hand, is a most complicated phenomenon. In the Antarctic, the conditions are very much simpler than in the Arctic, and, even there, the drift is far from being a simple function of the velocity and direction of the wind.

For the north polar basin, the distribution of the surrounding lands and islands, and the existence of well-pronounced ocean currents, complicate the ice-drift to such an extent that the possibilities of a successful study of the correlations between the anomalies of the meteorological conditions and the abnormal changes of the ice conditions is evidently most problematical.

The observations collected by the Danish Meteorological Institute and printed every year concern the ice conditions during the navigable season only and are naturally restricted to the peripheral areas of the frozen sea. In some waters, we have to deal with winter ice, which must melt away during the summer; in other waters it is old drifting polar ice which hinders navigation. To correlate these variable ice conditions, of the navigable season of some arctic seas, with atmospheric temperature data of distant stations is a task which can lead only to very uncertain results.

³¹ In the special reprint of the Nautical-meteorological Annual of the Danish Meteorological Institute, "Isforholdene i de arktiske Have, 1909," it is said:

"Off New Foundland and on the transatlantic steamer routes uncommonly much ice was observed, flocs as well as icebergs. As early as February there was much ice, and from March to July the conditions were more unfavorable, than they have been for many years. The icebergs held out uncommonly late, the navigation being much hampered at Cape Race as late as August. It was not till September that the ice commenced to decrease, but still many icebergs were to be met in Belle-Isle Strait and far off-shore off the Strait."

Nevertheless, comparing the yearly temperature departures of the Icelandic stations and Angmagsalik, on the east coast of Greenland, with the state of the ice in Denmark Strait and north of Iceland, one finds that a correlation is undeniable.

Now, why is the variation of Grimsey (Fig. 57) so much more accentuated than that of Berufjord or Vestmannö? It seems evident that the proximity of the ice must be the cause.

Consequently, the Icelandic consecutive temperature curves could be taken as an example proving the influence of the ice on the variation of temperature. The ice conditions of Denmark Strait must greatly influence the temperatures of Grimsey, especially some of the monthly means, by accentuating them one way or the other. It is not, however, the ice which causes the observed variations of temperature producing the formation of pleions and antipleions. The departure maps I have drawn show this plainly.

The changes of ice conditions are more or less local phenomena restricted to small areas; the formation and development of the pleions and antipleions, on the contrary, are a universal phenomenon.

CONCLUSIONS

In the case of the annual departures of temperature for the years 1891 to 1900, which I utilized in my previous investigations, I dealt with the results of observations made all over the world and gained therefore some precise knowledge of the distribution and extent of the pleions and antipleions, and found that the years 1893 and 1900 were particularly interesting, the first being a year of predominant antipleions and the second being a typical pleionian year.³²

In 1900, the pleions were not only very accentuated, with exceptionally high departures at their centers, but the areas they covered were fused together in such a way that the antipleions appeared as isolated patches on a pleionian background. The year 1900 was exceptionally warm, the temperature of our atmosphere being above the average, the negative areas being insufficient to compensate the excess of temperature of the positive areas.

In some cases,—the map for 1909 (Fig. 61) shows it plainly,—conjugated pleions form bands of very extensive dimensions. In other cases, there are intercrossing pleionian bands forming a real network with antipleionian patches between.

³² *Op. cit.*, p. 123.

Therefore, since, as has been demonstrated in this memoir, the Arequipa variation is not exclusively an equatorial phenomenon, but appears, more or less modified, in North America, Europe and even in the arctic regions, the question is whether the years of conjoined pleions do not correspond to crests of the Arequipa curve and whether the depressions of this curve do not correspond to years of isolated pleions in a net of conjoined antipleions. In fact, the maps for 1900–1909 show that the years 1904 and 1907, closely following the Arequipa depressions, are years of conjoint antipleions, and that the years 1900, 1908 and to a certain extent 1905, are pleionian years with isolated antipleions.

FIG. 31.—*Pleionian connections*

The existence of macropleionian variations, the close correlation of the pleionian phenomenon with the Arequipa variation, the compensating antipleions, and, finally, the dynamic character of these climatic changes, eliminate, it seems to me, the hypothesis attributing such changes exclusively to the presence of variable quantities of volcanic dust in the higher layers of our atmosphere.

Variations of the solar radiation must be the real and most important cause producing the changes of our climates and keeping them in a dynamic state.

The elaborate investigations pursued at the Smithsonian Astrophysical Observatory, and the Mount Wilson Observations in particular, give striking support to this conclusion.

In fact, considering the means of the solar constants, observed at Mount Wilson during the summer months of 1905, 1906, 1908, 1909 and 1910, and comparing the differences of these mean values with the correspond-

ing differences of temperature in Arequipa, one arrives at the conclusion that a difference of 1° F. corresponds to a change of 0.01 of the solar constant.

It would be premature to conclude that the brachypleionian, the pleionian and macropleionian variations are simply due to corresponding variations of the solar constant. Other factors may indeed complicate the phenomenon. Further research into the variations of the climates of Asia, South Africa and Australia, in particular, must be made before any definite conclusions can be reached. It is also evident that the seasonal changes of temperature, atmospheric pressure and rainfall have to be taken into consideration. I intend to do this.

In this paper, I have shown that in far distant regions of the globe, simultaneously with the appearance of the Arequipa crests, pleions are formed; that these pleions have a tendency to persist; that, in order to persist, one must displace another. Pleions and antipleions are correlated: if one moves, the other moves. In North America the displacements seem to be confined to the North American continent. In consequence, the pleions must pendulate from one side to the other. Moreover, the differences between the pleionian crests and the antipleionian depressions of temperature change. These changes of amplitude seem to be in immediate correlation with the equatorial changes of temperature.

The Arequipa curve may, therefore, be considered as a very convenient standard for the study of all the complicated phenomena of climatic variations, and of those observed in North America in particular.

It appears now perfectly evident that a more detailed study of the Arequipa variations will advance very greatly the problem of correlations between solar and terrestrial phenomena.

THE GENESIS OF CERTAIN PALEOZOIC INTERBEDDED
IRON ORE DEPOSITS¹

BY RAYMOND BARTLETT EARLE

(Presented in abstract before the Academy, 7 April, 1913)

CONTENTS

	Page
Introduction.....	116
Acknowledgments.....	117
Part I. A study and criticism of previous theories.....	118
The Silurian era.....	118
Iron ore deposits of the Clinton formation.....	120
Types of ore.....	120
Extent of deposits.....	121
Other Paleozoic deposits.....	123
Wabana deposit, Newfoundland.....	123
Torbrook and Nictaux deposits, Nova Scotia.....	124
Mira Valley deposit, Cape Breton, N. S.....	124
Summary of theories of genesis.....	124
Primary deposition.....	125
Secondary origin.....	129
Residual enrichment theory.....	129
Replacement theory.....	130
Application of recent investigations.....	131
Theory of original sedimentation.....	131
Sedimentary aspect of ore bed.....	132
Consequences of sedimentary theory.....	132
Field evidence.....	133
Inadequacy of sedimentation in open sea.....	134
Sedimentation in lagoons.....	134
Theories of replacement and secondary enrichment.....	135
Persistence of ore seams.....	135
Unreplaced limestone.....	135
Secondary enrichment theories.....	136
Simple replacement theory.....	136
Part II. Artesian replacement theory.....	137
Artesian conditions.....	137
Controlling factors.....	137
Circulation of artesian water.....	138
Typical sections of Clinton ore.....	139
Missouri.....	139
Alabama.....	139
Georgia.....	143
Tennessee.....	144

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	Page
Virginia.....	144
West Virginia.....	145
Pennsylvania.....	145
New York.....	146
Nova Scotia.....	147
Artesian conditions in the Clinton deposits.....	147
Porous layers.....	148
Impervious layers.....	148
Marine artesian slopes.....	149
Infiltration of meteoric waters.....	149
Ore conditions resulting from artesian slopes.....	150
Depth of deposits.....	150
Extent of deposit down dip.....	151
Wide distribution of deposits.....	151
Occurrence of oölitic and fossiliferous ore.....	151
Variations in chemical composition.....	151
Variations in texture.....	152
Variations in richness.....	152
Artesian replacement theory as applied to other horizons.....	152
Deposits of Wabana, Newfoundland.....	153
Deposits of Mira Valley, Cape Breton, N. S.....	153
General summary and conclusions.....	153
Part III. Bibliography.....	156

INTRODUCTION

The great economic importance of interbedded iron ore deposits has been recognized for many years. Two types of these ores may be cited as notable examples: first, and possibly most important, are the Clinton hematites extending along the Appalachian system of mountains for nearly two thousand miles and having their greatest development in the Birmingham district, Alabama; second, the Wabana hematite deposits, on and near Belle Isle, Newfoundland.

The great extent, commercial importance and scientific interest of these Paleozoic interbedded iron ore deposits has long made them a subject of painstaking exploration and study; the extensive development of them that has taken place during the last fifty years, and more especially within the last ten years, has made it possible to gather together a large amount of information of a detailed and accurate nature that under other conditions would have been impossible.

Underground mining has largely taken the place of earlier open-cut methods. At Wabana, for example, the ore is now being mined under the sea at a distance of two miles from the original open-cut workings.

In Birmingham and Attalla, Alabama; in Clinton, New York, and in many other places, the same conditions prevail, and hard ore underground mining has largely superseded the soft ore open-cuts.

Deep borings, in some cases nearly 2,000 feet in depth and several miles from the present workings, have brought to light conditions unknown in former times. Genetic theories, advanced originally from a study of outcrops and open-cut mines, undoubtedly would have been different, had the present data been available at the time. Yet with all the data accessible at the present time and much literature within reach, the question of the genesis of interbedded Paleozoic iron ores, and more particularly the Clinton ores, is still in controversy. Men of established reputation and wide experience adhere to theories sharply at variance with one another. At least two and possibly three such theories are still advanced and have the active support of men prominent in the mining and geological world.

The practical importance of an accurate knowledge of the origin of these ores must not be overlooked. Upon such knowledge depends the interpretation of conditions underground below the present zone of mining, the depth to which the ore may be expected to go and the continuance or change of richness of the ores.

It has been the purpose of the writer to include in this paper a brief review of former theories and to discuss these theories in relation to recent field and laboratory developments, showing where they fail to meet certain conditions now known to exist and therefore must to some extent be altered or superseded.

Further, the paper proposes and elaborates a theory of genesis which the writer has worked out in the field and laboratory and which, in order to separate from other theories and to avoid confusion, he calls the "Artesian Replacement Theory."

In brief, the writer attempts to maintain the following thesis: that the Paleozoic interbedded iron ores of eastern North America, and more particularly the so-called Clinton ores, are replacements of porous strata of ordinary mechanical sediments by iron oxide, the agency being ferruginous waters acting under artesian conditions.

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Hovey, Prof. A. W. Grabau, W. M. Bowron, W. C. Phalen, Prof. J. J. Stevenson, Prof. C. P. Berkey, J. Bewley and H. V. Maxwell.

The writer made use of slides loaned by Prof. C. H. Smyth, Jr., including those used as a basis for the sedimentary theory; also slides loaned by S. W. McCallie, State Geologist of Georgia, and a set of slides from E. F. Burchard, of the United States Geological Survey.

The field work was provided for by a grant from the John Strong Newberry Fund of the New York Academy of Sciences.

PART I. A STUDY AND CRITICISM OF PREVIOUS THEORIES

THE SILURIAN ERA

Whether the events that took place during the Silurian era were such as could give rise to immense deposits of iron ore precipitated as original material and thus forming contemporary sedimentary iron ore beds, or whether fossiliferous limestones and sandstones of a nature favorable for the later penetration of iron-bearing solutions were formed during a portion of this era, cannot probably be determined without detailed study of probable land and sea conditions at that time; but if any extended study of these deposits is to be made, a knowledge of land and sea areas and a study of conditions that affected different kinds of deposits at the time the inclosing strata were laid down seem not only desirable but important.

According to Dana, the North American continent at this time consisted of a broad land area extending from Alabama northward east of the present Appalachian system through Georgia, Tennessee, the Virginias, Pennsylvania and into New York, there turning westward, skirting the Great Lake region, then turning in a more or less southerly direction through a portion of Wisconsin, then abruptly turning northward and running far into Canada. The southern and eastern portions of this continent must have extended far out into the Atlantic ocean. On the west, was a fast closing sea area shut off from the cold waters of the arctic regions by rather extensive areas of the Archean shield. This left an immense interior sea and a gulf or bay nearly 800 miles long, favorable to the presence of warm currents which undoubtedly greatly influenced life in the waters and temperature conditions on the land. That these conditions were responsible to a large extent for the texture, composition and distribution of the Silurian strata, we cannot doubt.

Quoting from S. W. McCallie (216, p. 162):

"The region, however, of this tumultuous sea, with its rapid, moving currents, appeared to have been rarely of long duration. Scarcely had the deposits

of sand and pebbles been fairly inaugurated, when the work was brought to a sudden close by a deepening of the waters, or a change of sediments. The enfeebled currents were now enabled to carry only the finest sands and clays, the materials of which formed the innumerable layers of shale. The later condition seems to have predominated throughout the entire Clinton epoch, but the frequent occurrence of sandstone marks intervals of time and less often repeated, the conditions favorable for the deposition of sands and clays gave place to conditions favorable to the deposition of limestone. The last named conditions point to the clearing of the waters, and probably also the deepening of the sea. The thinness of the individual limestone beds would indicate that the conditions favorable for the deposition were of short duration. Yet, at the same time, the extended area over which they often occur shows that the conditions were widespread, and not confined to certain special localities. In the entire series of Clinton rocks, from the beginning to the end, we here see no evidence of sudden upheavals or tilting of strata. The character of the sediment points only to general oscillations of the sea floor, many times repeated."

At the close of the Clinton, no marked changes took place till the close or near the close of the Niagaran period; then came a gentle uplift, as shown by the erosional unconformities. This emergence continued well into the Middle Silurian. Before the close of the Silurian period, two more periods of elevation have been recorded.

The layers of sediment that formed a portion of the epicontinental shelf at the close of the Clinton era thus emerged from their original position and at the close of the Niagaran became a part of the coastal plain, the layers of the Clinton formation outcropping and thus placing their catch basins in a position favorable for the easy penetration of meteoric waters charged with iron-bearing solutions.

The following correlation table has been taken from Professor Grabau's work (128, p. 87):

<i>Siluric</i> : Upper or Monroan.....	Hiatus and disconformity

	Akron dolomite
	Bertie waterlime

	Hiatus and disconformity
Middle or Salinan.....	Hiatus and disconformity

	Salina.... Camillus
	Syracuse
	Vernon
	Pittsford

Lower or Niagaran.....	Hiatus and disconformity Guelph Lockport Rochester Clinton
------------------------	---

(Disconformity refers to an erosional unconformity.)

The important points with reference to iron ore deposits to be deduced from the above described conditions appear to be as follows: first, a thick series of sedimentary beds of rapidly changing texture and composition, clays and shales, sandstones and longer continued but less frequent limestone deposits; second, an irregular shore outline with consequent effects upon shape and size of sedimentary beds; third, a large area open to the constantly changing waters of moving and probably rapidly moving ocean currents from the south; fourth, to the east, land areas of the older crystalline rocks of both acid and basic types, from which the iron salts were dissolved in the course of weathering; fifth, a long period of slight oscillations of the sea floor. After the deposits had been formed, they were slowly elevated, and land areas were increased by a gradual emergence of the sedimentary beds. No violent or pronounced folding took place until the beginning of the Appalachian revolution, but mild disconformities followed the slight uplifts accompanied by slight tilting.

Erosion of the strata on this coastal plain gave access on the part of the ferruginous waters to the porous beds, in which the water soon developed artesian conditions.

IRON ORE DEPOSITS OF THE CLINTON FORMATION

The Clinton iron ore was first discovered in or near the town of Clinton, New York. It was found later to be very common throughout the Upper Silurian, and the same type occurs also in other geological horizons. It has been traced extensively throughout much of eastern North America along the folds of the Appalachian system.

The Clinton ores are usually found interbedded with slates, shales, sandstones and impure limestones.

TYPES OF ORE

The Clinton iron ores are known by various names according to texture, composition and location.

The fossil ores (Plates VIII, IX, XVI) are composed of large masses of marine fossils, such as bryozoans, corals, crinoid stems, brachiopods and many other characteristic fossils of that age. These fossils are usually

found in a very fragmental condition and have been wholly or partly replaced and coated and cemented with iron, or a mixture of iron oxide and calcite cement.

The oölitic ores (Plates X, XX, XXI) are composed of oölites of hematite cemented together like the fossil ores, but containing the peculiar oölitic structures which have often been referred to as resembling fish roe. The oölites are made up of a nucleus of quartz or other mineral, coated in concentric rings or spheres with iron, usually in the form of red oxide.

The flaxseed or "seed" ore is really oölitic ore and has the same peculiar structure. In some cases, however, the term refers only to a smaller grained oölite, such as that in Ohio and Wisconsin.

Dyestone ore is the name given to the Clinton red hematite of Tennessee and some other regions because of the fact that it has long been used as a paint or dye; and even in very early times it was mined in a small way by near-by inhabitants for such purposes.

The red flux beds refer to a lean seam or seams of fossil ore in northern New York, the highest iron-bearing seam of the New York Clinton formation, and found typically at Clinton, New York.

Soft and hard ore are names used particularly for southern deposits, to denote the difference between unaltered ore and that which, as a result of weathering and a loss of soluble materials like calcite, has left a residue rich in iron oxide and high in silica; the resulting soft ore being rather more porous than the hard, and found at or within a few hundred feet of the surface. The hard ore, on the other hand, is called hard, not because of its actual hardness, but because it runs high in lime and has not been affected by surface changes due to weathering. If we were to dissolve the lime from hard ore, the result would be a residue rich in iron and silica and precisely like the soft ores. Because of the value of lime in fluxing iron ores, the hard ores of lower grade are much sought and extensively mined. The soft ores, originally supposed to be the only valuable ores, have been for the most part worked out; and the old open-cut mines have given way to the underground hard ore mines.

EXTENT OF DEPOSITS

One of the most interesting problems to be solved in a study of the origin of these iron ores is how any single theory of origin can account for a line of deposits extending over such an enormous area. Following the shoreline of the old Silurian land areas bordering the epicontinental sea, we find deposits intermittently all along the line (Plate VII).

In Wisconsin, the ore occurs in Dodge County, attaining its greatest

importance at a place called Iron Ridge. This Wisconsin deposit is isolated and unlike the Clinton deposits found elsewhere, both in the shape of the body which appears to have resulted from filling of a local basin, and also in respect to the size of the oölites, which are smaller than the oölites found elsewhere and are peculiarly flattened. Professor Grabau of Columbia University (128, p. 77) has suggested that they may be wind-blown deposits in the nature of sand dunes, which have been buried and later impregnated with iron ore.

The ore next appears in New York, beginning near Rochester, where it can be seen in the Genesee Gorge in Monroe County, and then extending eastwardly through Wayne, Oneida, Madison and Herkimer Counties. In this state, the ore is being steadily mined at Ontario and Clinton. The most extensive development is that of the Borst properties, in what appears to be a small bay of the old Clinton sea, covering possibly 2,000 acres near Clinton. Southward, we find the Clinton ores again outcropping in Pennsylvania. Here the deposits extend in a broken belt across the central and southern parts of the state, including Montour, Snyder, Juniata, Blair, Bedford, Mifflin, Centre, Fulton and Huntingdon Counties. These occurrences form a belt of several parallel ridges which run southward into Maryland, where they appear in two beds in Allegany County. The ore then passes into West Virginia, where it appears in Mercer, Monroe, Greenbrier, Pendleton, Hardy and Grant Counties. These West Virginia deposits have been but little used or explored.

The ores are then found in a few isolated sections along a line passing through the western part of Virginia and including Wythe, Giles, Bland, Tazewell, Russell, Scott, Lee and Wise Counties. These deposits have been worked to a limited extent but are for the most part in a very undeveloped condition.

The ore belt then passes through Tennessee, extending across the entire width of the state, a distance of over 150 miles, into Georgia. The Tennessee ores occur in Claiborne, Campbell, Rhea, Roan, Sequatchie, Hamblin and Marion Counties. Here, owing to the much-folded condition of the strata, many seams in parallel ridges appear running in a southerly direction into Georgia. In Georgia, the ore is found in Dade, Walker, Chattooga, Whitfield and Catoosa Counties. The ores of Dirtseller, Gaylors, Taylors Ridges and Lookout Mountain all are of considerable interest.

From Georgia we find the ore extending into Alabama, where it reaches its greatest development in the Birmingham district. It is found in Shelby, Tuscaloosa, Bibbs, Jefferson, Dekalb, Etowah and St. Clair Counties.

Two other separate occurrences of this Clinton ore have been noticed. One of them is a short spur extending from Kentucky into the southern portion of Ohio. In Kentucky, it appears in Bath, Montgomery and Fleming Counties. In Ohio, it is found in Clinton, Adams, Highland and Muskingum Counties. The other occurrence, which is of no present importance, is that of Missouri, where in Holt County a deep borehole revealed a seam of fossil ore in what appeared to be Clinton strata.

From this outline, it is clear that these deposits are of great extent, and that this feature must be reckoned with in accounting for their origin.

OTHER PALEOZOIC DEPOSITS

WABANA DEPOSIT, NEWFOUNDLAND

The Wabana deposit, one of the largest deposits of interbedded iron ore in the world, is located on Belle Isle, in part, and extends for a considerable distance under the waters of Conception Bay, Newfoundland. The properties have been estimated to contain 3,635,000,000 tons of hematite iron ore (170, pp. 745-752).

Conception Bay on the east is bounded by a shore of Huronian strata, which overly an anticline of Laurentian age, but are not conformable with it. The western shore of the bay is regarded as pre-Cambrian. Between these shores is a great synclinal trough of sandstones, slates and shales of Cambrian age. The upper strata forms Belle Isle and contains six beds of hematite, two of which are being worked at present. They show the following section (SYMONS; 328, p. 1009) :

	Feet	Inches
Shales	56	..
Hematite	1	..
Sandstone	5	..
Hematite	1	3
Sandstone	2	..
Hematite .....	..	3
Sandstone	2	..
Hematite .....	..	3
Sandstone	2	6
Hematite	1	..
Sandstone and shale.....	3	..
Hematite	4	..
Sandstone	46	..
Hematite	9	..
Sandstone and shale.....	280	..
Hematite	12	6

The ore consists of a dense red hematite, high specific gravity, with bright metallic luster and a highly developed cleavage. The ore is of the non-bessemer type.

These deposits are now being mined two miles from the outcrop, under the sea. The quality of the ore has slightly improved with depth.

TORBROOK AND NICTAUX DEPOSITS, NOVA SCOTIA

Several beds of hematite of a similar type to the regular Clinton ores have been located at Torbrook and Nictaux, Nova Scotia. The two principal beds are the so-called "Shell" vein and the Leckie vein. Sections of this deposit may be found on page 147.

MIRA VALLEY DEPOSIT, CAPE BRETON, N. S.

The ore deposits of Mira Valley, Cape Breton, N. S., are interbedded iron ores much like the Clinton deposits. Professor Woodman in his report (356, II-12-(3)) says in reference to them:

"The iron-bearing minerals are magnetite, red compact hematite, specular hematite, and possibly siderite in small amount. They occur in bands, interstratified with the sediments. In places they grade imperceptibly into the latter across the bedding, and often downward or on the dip and longitudinally or on the strike. . . . These ores furnish perhaps the best examples known of partial and interrupted replacement."

Section on McKinnon farm:		Inches
Slate wall.....		...
Red hematite.....		3.0
Slate		1.5
Quartzite		1.5
Magnetite		1.0
Slate		0.5

Ronald McDonald farm:		
Slate .....		...
Ore		1.0
Quartzite		2.0
Slate		1.0
Ore		1.5
Slate .....		...

SUMMARY OF THEORIES OF GENESIS

The origin of the Clinton ores has long been the subject of dispute, and even to-day, with the large amount of data available, we find considerable diversity of opinion. Mining men, owners of mines and those

interested in the financial success of the various properties naturally lean for the most part to the theory that will best support their contention that the richness of the ore body will not diminish with depth. The views maintaining this contention seem to be well sustained in certain places by some of the facts developed in the course of actual mining operations. In other localities, however, data appear to contradict this view to some extent.

A theory which would apply to all of the Clinton deposits must account for the oölitic character of some ores and the fossiliferous character of others, for the occurrence of the ores in conformable strata, for the difference in lime and silica content in the various ore beds and within the same bed, for the presence of waterworn pebbles and grains of sand, for the soft and hard ores so common in the southern localities and for the compact and cleavable ores of some of the northern deposits. To find a theory that will reconcile all of these variables has thus far been impossible, and most writers have admitted that to a limited degree other theories besides their own may have some value.

Three principal hypotheses have been advanced to account for these Clinton ores: (1) the theory of original deposition, which has been referred to as the sedimentary theory; (2) the residual enrichment theory; (3) the replacement theory. Of these theories, the first has the greatest number of advocates. It has the merit that depth would not affect the value of the deposits.

PRIMARY DEPOSITION

The advocates of the primary deposition theory believe that the Clinton ores were deposited contemporaneously with the inclosing rocks, in the form of chemical precipitation at the bottom of the sea. Some claim that the iron was originally dissolved from the ancient crystalline and metamorphic rocks of Appalachia Land. The ferruginous waters were carried into inclosed or partly inclosed shallow seas or basins. The iron salts were slowly oxidized and precipitated gradually, forming concentric layers of iron about particles of sediment on the sea bottom. As the sediments varied in kind and texture in different places and at different times, the nuclei about which the iron concretions were formed differed. In some layers, the oölitic structure surrounded grains of well-rounded quartz sand; in other layers, broken fragments of fossils such as crinoid stems, bryozoans, brachiopods or corals were inclosed in iron concretions. It is claimed by some that where calcareous fossils were present, some replacement occurred, but only while the process of original sedimentation was in progress.

The advocates of this theory are numerous. In order to set forth the arguments given in favor of this theory, the writer quotes from several of its leading advocates.

Quoting E. C. Eckel (37, pp. 32-33) :

"The principal facts supporting the theory of sedimentary origin may be briefly summarized as follows :

"1. In mining from slopes running down on the dip of the ore bed, when once the limit of surface weathering is passed—and this may be at any point from 1 to 100 feet below the outcrop—no further important change in the ore is found with increasing depth; though a number of mine workings are now close to 2,000 feet from the outcrop.

"2. A number of borings in Alabama have struck the ore at points from one-half to one mile back from the outcrop, and at depths of 400 to 800 feet below the surface. The ore encountered in these borings was hard ore of the usual quality, and not merely a 'ferruginous limestone.' Several borings in New York have struck Clinton ore at distances of from 10 to 15 miles back from the outcrop. These borings showed good ore at depths of 664 to 995 feet below the surface.

"3. The physical character of the oölitic ore cannot readily be explained on any replacement theory, while the formation at the present day of original oölitic materials is a matter of common knowledge.

"4. The occurrence of fragments of the ore in overlying beds of limestone in the Clinton formation as described by Smyth, points to the fact that the ore had been formed prior to the deposition of this limestone.

"5. If the replacement theory were accepted, one would expect that the ore beds would show a greater vertical range; that is, that they would at places occur in rocks of other than Clinton age. Throughout their entire extent, the Clinton beds are closely associated with Silurian and Devonian limestones and shales, some of which offer excellent receptacles for the replacement deposits, but the characteristic red ores are confined to the Clinton itself."

The author goes on to say that primary replacements did not exist to any great extent, but, although no definite proof has been found, it is probable that some secondary replacement has since taken place. Leaching, of course, is noted. Eckel has done a very considerable amount of work on these ores while engaged in the economic work of the U. S. Geological Survey, and, although his principal investigations were upon the deposits of the southern states, he included a wide extent of Clinton deposits in his special study, and his views must be recognized as founded upon accurate information and a broad knowledge of the literature available.

According to Professor C. H. Smyth, Jr. (317), the replacement theory for the origin of the Clinton ore was not substantiated by the facts in the field. The calcareous rocks would certainly have caused the iron to be precipitated while it was passing through them, yet the ore is

found in places directly underlying limestones and shales. Concretions in the lean ore were found to be as ferruginous as those found in the richer ores; accordingly, the substitution took place before the fossil fragments were consolidated into a bed by the cementing material. If the ore is formed by a process of replacement, it should contain some ferrous carbonate, yet this has never been found. The iron did not come from above, for the Clinton ore beds are often horizontal, with no chance for the action of downward-circulating waters. There is no doubt that the ore was laid down in the form of an original precipitate at the same general time that the inclosing sediments were deposited. It is likely that there has been some enrichment of the deposits by the removal of calcium carbonate. The iron is secondary only in respect to the organic fragments, but primary with respect to the ore deposits as a whole. Weathering has contributed to the present condition of the formation as we find it to-day in some localities. Iron oxide and silica were deposited together from solution in meteoric waters. Organic material caused the retention of the iron in such waters. There is a connection between silicic acid, iron and organic acids in the soils, and a deposition of iron and silica together. Oölites were not originally calcareous.

Smyth has probably been quoted more than any other writer in support of the sedimentary theory of origin. It is certain that the careful microscopic work done by him is well worthy of careful consideration before coming to any final conclusion in regard to the origin of these deposits. Most of Smyth's work was founded on a study of the Clinton ores of New York.

Quoting D. H. Newland and C. A. Hartnagel (234, p. 50):

"The evidence in support of both views has been traversed very thoroughly by C. H. Smyth, Jr., in a paper which represents as well the results of long experience and close study of the Clinton ores both in northern and southern districts. There can be no doubt after an impartial perusal of Professor Smyth's paper that the theory of sedimentary origin is fully substantiated for most of the occurrences. For the ores under present consideration, this is the only explanation at all compatible with the conditions.

"The stratigraphic features presented by the New York section of the Clinton do not lend themselves to the conception of vertical circulations of ground water such as would be required to dissolve and carry iron from the overlying strata. The ore beds everywhere lie nearly horizontal; their dip is universally toward the south, at an angle no greater probably in many places than that given by the contour of the original sea bottom on which they were deposited. At no time in their subsequent history have they been steeply inclined. Moreover, they are overlain by thick shales not readily permeable to water. Underground flowage must necessarily be limited and be dependent for the most part on the cropping out of the more porous strata-like limestone and sandstone layers. Thus it is directed rather along the bedding planes than across

them. Below the ore, there is also more or less shale intervening before the top of the sandstone and conglomerate basement is reached."

G. P. Grimsley (130, p. 74) :

"The rocks of the Clinton series in this state are shales, clays, sandstones and an absence of limestone. If there was originally a bed of limestone now replaced by ore, the stratum was a very irregular one, varying in thickness from 6 inches to 3 feet. It expanded and contracted from place to place in a most irregular manner; a relation very unusual for limestone, but often present in sandstones and other shallow water rocks. By the theory of original sea deposition of this iron ore, it would be formed in the Clinton sea in the same manner as sandstones and shales. The iron was precipitated and mixed with sand and clay in which fossils were preserved. The oölitic structure would imply a concretionary deposit, the iron ore being precipitated around sand grains in concentric form. In some portions of the sea, as in the Keyser area, there was only a slight precipitation of iron in the sand.

"The difficult factor to account for in this theory is the quantity of iron available for this deposit in the Clinton sea, apparently not duplicated at any other time before or since. There must have been at this time an exceptional quantity of iron present; its source is difficult to explain. There are thus encountered in both theories factors almost impossible to account for; but it seems to the writer that the theory of original deposition offers a more satisfactory explanation of the origin of these West Virginia Clinton ores than that of replacement."

One of the most complete publications on the Clinton ores has been made by S. W. McCallie (216) for the Georgia Geological Survey. He agrees with Eckel and Smyth in placing the origin as original sedimentary deposition, but differs from them as to the source of the iron. He maintains that it came originally from large deposits of glauconite marl.

Both J. S. Newberry (232) and T. C. Chamberlin (53) conclude that the Clinton ores of their states were formed by original deposition of their iron content, similar to the Swedish lake ores.

H. D. Rogers (290, p. 729) :

"The regular ores of the Surgent (Clinton) series are to be regarded as among the permanent constituent strata of the formation, and as having originated with other sedimentary materials in the form of very extended, but thin, sheets of ferruginous matter, covering at successive epochs the wide floor of the quiet Appalachian sea."

He goes on to say that the source of the oxides has not been determined. He acknowledges that much secondary enrichment has taken place by enormous quantities of ferruginous matter diffused in marls, slates and shales in contact with the ore bodies, being dissolved in the form of sulphate and then redepositing the iron in the ore beds, reaction

with the lime of fossils converting it to peroxide. This secondary enrichment is plausible because where the outcrop, the slope of the ground, the thickness of the overlying strata and other conditions are favorable to considerable infiltration of surface water, the ore carries a higher amount of iron than at less favorable places. The fossils often form one-half of the total weight of the ore; it is obvious that if part of the lime thus contained is dissolved out, the remaining peroxide of iron will form a much larger percentage of the total bulk of remaining material.

SECONDARY ORIGIN

Residual Enrichment Theory

The residual enrichment theory starts with the supposition that the ore beds were originally limestones rich in iron, that by a process of leaching the lime carbonate was partly or wholly removed, and that the iron, together with the insoluble material, was left in a much more concentrated form.

Similar effects are known in tropical countries; in Cuba, for instance, where silica by a process of weathering known as laterization has been removed from iron-bearing rocks, leaving the iron and insoluble portions rich enough to be classed as an ore and mined profitably.

I. C. Russell (292, pp. 22-23):

"Portions of the Silurian rocks of Alabama, readily recognized as limestones when unweathered, are easily mistaken for sandstones and shales when only their weathered outcrops can be seen. The Clinton ore, or fossil ore, interbedded with strata of shale and sandstone forms one of the most characteristic beds in the Upper Silurian rocks of Tennessee and Alabama. In the mines of Gadsden and Attalla, Ala., where Clinton ore is worked, the strata are highly inclined (a dip of 70 to 80 degrees to the southeast prevailing) and well exposed for study.

"The outcrops of the beds are soft, porous, highly fossiliferous ore, which has a deep brownish red color, and is easily worked and easily smelted. The ore at Attalla retains this character to the depth of about 250 feet, measured down the slope, and then changes to a hard, compact, ferruginous limestone, rich in fossils. The marked difference in the character of the ore in the upper portions of the mines as compared with that of the lower portions is due entirely to weathering. This is shown by its chemical composition. Two typical samples of the ore, selected by me—one from near the surface, representing the ordinary character of the soft ore, and the other from a depth of 250 feet, representing the hard ore, but not the most calcareous variety—gave on analysis the following percentages of iron, lime and carbonic acid, after drying at 105 degrees Centigrade:

	At surface	250 feet
Fe	57.52%	7.75%
CaO	1.38%	47.64%
CO ₂ .....	.30%	34.90%"

Eckel (37, p. 33) claims that Russell was mistaken and that the Attalla ores do not vary with depth.

Replacement Theory

The replacement theory holds that the iron content of the Clinton rocks in the form found at present has resulted from a replacement of lime carbonate by iron, long after the rocks had been deposited. The iron was introduced by descending waters charged with iron which they had dissolved out of overlying ferruginous rocks.

J. J. Rutledge (293, pp. 254–255) :

“The conclusion that the iron content of the Clinton iron ore beds of Stone Valley, Penn., is due mostly to replacement by removal and enrichment, seems unavoidable, when it is considered that but a portion of the fossiliferous limestone or of the hard ore is found to contain iron oxide when examined in thin sections under a microscope. Calcite cement makes up by far the greater portion of the section.

“An analysis of the limestone shows that it contains but 2.12 per cent of FeO and 2.35 per cent of Fe_2O_3 . These seem much too small an iron content to yield as rich an ore as the soft ore, simply by the removal of the calcium carbonate. Field conditions such as the occurrence of weathered shales, dull colored clays and iron-stained sandstones, prove that the action of replacement is still going on.

“The iron came originally from the overlying shales and was transferred later to the beds of fossiliferous limestone.”

The following reasons are advanced by Rutledge for the statement that the addition of iron was not due merely to the removal of the limestone, as would be the case under the enrichment theory :

“(a) The character of iron ore concretions where associated with silica.

“(b) The invariable association of the soft ores (rich) with the leached, decolorized shales and the hard (lean) ores with unweathered, bright red shales.

“(c) The relations of the ores to the shattered sandstones and to the topographic situation of the ores.

“(d) The fact that analogous replacements are now going on in the Medina formation.

“(e) The observed progressive steps in the transformation of the limestone to an ore, which may be followed in the field, in the sections under the microscope and in chemical analyses.

“(f) The absence of conditions such as local crumpling, including a shrinking of the strata, pointing to a relative rather than an absolute enrichment of the ores.”

I. C. White (198, pp. 135–137) :

“The iron has evidently been filtered into the bed as the lime has been

filtered out of the bed, otherwise the percentage of iron in the bed would not diminish below drainage level.

"Wherever the ore is valuable the inclosing rocks are very much weathered; the lime rocks are changed into clay and the shales overlying the ore are bleached almost white; their iron having presumably been transferred to the ore bed. And this is a reasonable way of explaining the fact that the ore bed does not always keep the same place in the series, for any bed can become an ore bed, provided it is so situated as to be a water-bearer and recipient of the iron-leachings."

A. F. Foerste (110, pp. 28-29):

"As a rule the iron has replaced the substance of the bryozoan itself; all the stages between partial and complete replacement may be noticed, the most complete stages being of course found in the purer ores. Usually, corresponding changes are observed in the cement which binds the oölitic grains together into a solid mass. It is evident in these cases that the origin of the oölitic structure is not due to a concretionary segregation of iron particles, but finds its explanation in the gradual replacement of the lime of the fragmental fossil bryozoans, particle by particle, by the iron ore."

N. S. Shaler (303, p. 163):

"The ores were not included in the present iron-ore beds at the time of their deposition, as conditions varied so much at different points that this would have been impossible. The ore-occurrences are due to replacement of limestone beds by iron-bearing solutions derived from overlying shales. The iron could not have been deposited as far from the shore as the limestones were."

J. P. Kimball (190, p. 355):

"Parts of thin fossiliferous limestones of the Clinton group of strata are often replaced by red and brown ferric oxides from extraneous sources.

"This replacement has been wrought especially in steep dips by infiltrations from drainage of adjacent ferruginous strata, partially of an inferior series outcropping topographically higher in the flanks of these parallel ridges."

APPLICATION OF RECENT INVESTIGATIONS

THEORY OF ORIGINAL SEDIMENTATION

Even though it may be demonstrated that the oölitic hematite can be successfully synthesized in a chemical laboratory in open agitated water; even though oölitic formations such as the sand of the Great Salt Lake in Utah and the brown iron oölites of the Swedish lakes are being formed in open water to-day; yet no matter how plausible the theory may be in most respects, if a single factor prevails that would be impossible under conditions necessary for original deposition of the iron ore beds, it is

enough to discredit the correctness of the sedimentary theory and to force us to look elsewhere for an explanation of the origin of these formations.

Sedimentary Aspect of the Ore Beds

That the general appearance of the ore beds would give the impression that they must be regular sedimentary iron-ore beds laid down as the advocates of sedimentation suggest, cannot be doubted. Clean contacts, lens-shaped deposits, widespread occurrence, separated individual iron-coated oölites, non-ferruginous sandstone and limestone beds overlying some of the ore beds and underlying others, all would tend to give weight to the sedimentary hypothesis. Before the theory can be considered as proved, however, it must account for certain conditions that appear to the writer irreconcilable with any theory based upon original deposition.

Consequences of Sedimentary Theory

In the first place, let us apply the sedimentary theory to the oölitic hematites that are so common in New York, Virginia, West Virginia, Kentucky, Ohio and Wisconsin. Under the sedimentary theory, it is assumed that the Clinton Sea was heavily charged with iron salts in solution, and that, as sediments were being laid down along the shallow and gently inclined shore slopes, myriads of sand grains under the influence of considerably agitated waters were coated with layer after layer of iron oxide, which in many cases alternated with silica. These iron-coated grains finally accumulated into beds in the same manner as any sand stratum would accumulate and were then cemented by more iron and calcite into solid beds or layers of sedimentary rock like any other sedimentary deposit.

For the sake of argument, let us assume that such conditions did exist. If the sea-water contained enough iron in solution successfully to coat grains of sand until they formed a bed several feet in thickness, would it not be reasonable to suppose that all sediments laid down simultaneously would be coated, impregnated or at least stained with iron? Would not all lenses of clay and shale and limestone be completely saturated with the same iron-bearing sea-water that coated the mass of oölites? Would it be possible for any portion of the shore deposits along the entire length of the Clinton Sea to have escaped without leaving permanent evidence of the presence of such large quantities of iron in solution in the sea-water—iron sufficient to cause deposits within a comparatively short period extending for nearly two thousand miles along the shore, many miles out to sea and in some cases many feet in thickness?

Field Evidence

In a small seam of oölitic hematite about eight inches in thickness located at Big Stone Gap, Virginia, the writer discovered what at first appeared to be a small boulder (Plate XI, fig. 1) entirely surrounded by iron oölites. Upon removing the stone and breaking it, he found that instead of being an ordinary boulder, it was an original formation, such as is often present in beds of loose sand that have been penetrated gradually by mineral-bearing solutions and consolidated by the well known process of cavernous consolidation, leaving loose sand-filled cavities (Plate XI, fig. 1). The "boulder" was well filled with practically pure loose quartz sand, with no iron-coated or hardly even iron-stained grains (Plate XI, fig. 2) and was merely the first of several also similarly sand filled. Here we have a local accumulation of sand made up of quartz grains entirely surrounded by iron-coated oölites, yet completely ignored by the iron-charged solutions and not even consolidated. A little farther on in the same seam, another small mass of yellowish white sand was found, which was partly consolidated but had not been penetrated by the solutions that coated the surrounding oölites (Plates XII, XIII).

If we still believe that the iron-bearing solutions were a part of the sea-water, how can we explain two sets of different consolidations, one with iron the other without iron, from the same source and at the same time as the surrounding conditions seem to indicate in this case? Let it be emphasized that these occurrences are situated not at margins of ore seams, but well within a distinct stratum of hematite.

In Clinton, New York, in a single hand specimen, the writer found oölites coated with iron oxide and other oölites coated with a green mineral in concentric layers (probably an iron silicate, greenolite) and still a third type of oölite composed of a quartz nucleus, then a ring of iron oxide, then a thicker ring of the green mineral and finally another ring of iron oxide. In a seam in Birmingham, Alabama, a single slide of the Clinton ore shows a calcite-coated oölite and an iron-coated oölite side by side. How would it be possible for the iron-charged sea-water to distinguish between different grains of the same mineral and coat one with one substance and its neighbor with an entirely different mineral?

At Niagara gorge, we find the Clinton series of limestones, shales and sandstones, but no evidence of iron-ore seams. This indicates that the iron-bearing marine solutions had suspended operations at this point, and yet had been active as far west as Ohio, Wisconsin and Holt County, Missouri.

Finally, in applying the sedimentary theory to the fossil-ore beds, we

find conditions similar to those prevailing in the oölitic strata; limestones untouched by iron-bearing solutions, but with overlying and underlying iron-ore seams; lenses from a few inches to many feet in length composed of limestone with only a slight marginal penetration of the iron, and yet entirely surrounded by iron ore (Plate XIV, fig. 1). In places, fractures in the limestone beds have been penetrated by iron and the walls of the breaks lined with ore. In other occurrences, the iron has followed seams or laminations in the limestones and has replaced the limestone along these planes of weakness (Plate XV).

A generally prevailing condition of apparent replacement in all stages is found in both fossiliferous and oölitic beds, in which both calcite and quartz show corrosion and replacement (see photomicrographs, Plates XVI, XX, XXI).

Inadequacy of Sedimentation in Open Sea

The conclusion seems justified that, whereas widespread similarity of conditions should be expected, with unbroken evidence of the presence of marine iron-bearing solutions in the sedimentary beds (whether of sandstone, limestone, shale or clay), yet the reverse conditions actually exist, for (1) small lenses of loose sand untouched by iron-bearing solutions are found, which, under the conditions imposed by any sedimentary theory, could not have been free from the iron; (2) two unlike consolidations, one without iron, the other surrounding the first and completely charged with iron—a circumstance that would have been impossible under the sedimentary conditions pointed out by the various advocates of marine deposition of iron ores; (3) differently coated oölites in the same immediate locality would hardly seem possible under such a theory; (4) the penetration of iron into seams, lamination planes, weakened strata, mudcracks and fissures running off from the main ore beds could hardly be explained under theories depending upon a primary origin of the ores.

Sedimentation in Lagoons

In regard to a growth within inclosed lagoons or basins of shallow water, the field evidence in some places may bear this out. The writer's observations, however, have seemed to show much active wave erosion and considerable rather violent agitation of the sea-water. This is illustrated by what appear to be two well-formed stacks which could only have been shaped by wave erosion; one at Clinton, New York, and the other at Red Mountain, Birmingham, Alabama. Further evidence might be suggested, as, for example, the existence of several kinds of varieties of coral which

do not thrive in the still waters of inclosed basins but require agitated waters in the open sea. In places, also, the sediments contain a large amount of water-worn material, fossils badly broken and coarse-textured conglomerates. So, although we do see in places such testimony as Professor Smyth (317) has suggested, yet we find also much evidence of quite different conditions; and, therefore, it seems to the writer that little importance can be attached to the supposed basins as an aid to the determination of the origin of these ores.

THEORIES OF REPLACEMENT AND SECONDARY ENRICHMENT

Persistence of Ore Seams

The question of depth and distance from the outcrop to which the ore is known to extend is an interesting one, and the facts are inconsistent with the theories of secondary enrichment and replacement, where such theories depend upon leaching of slates and shales or vertical descent of ground waters. One boring has shown good ores, 1,902 feet deep and two and one-half miles from the outcrop; another over 800 feet deep and more than ten miles from outcrop and with a very low dip. The writer is inclined to agree with Professor Smyth (*loc. cit.*) in part in regard to such data; but as to using this great depth as an argument in favor of original deposition, he cannot convince himself that it applies. Some of the deposits in that event must have extended into waters of very considerable depth and distance from shore; and as depth increased, the amount of iron necessary for keeping up the same degree of richness as nearer to the shore must have been great indeed. It would seem highly improbable that these iron-bearing marine waters could circulate over and through the sediments without becoming diluted in the great expanse of water, as currents carried them far out to sea. The present writer would, on the other hand, lay claim to the argument of great depth in support of his ideas of origin, which differ widely from those of the advocates of original deposition.

Unreplaced Limestone

Finally, as to the argument that some overlying beds of limestone would be excellent for replacement of lime by iron and yet remain practically untouched with clean-cut contacts although in close proximity to iron-bearing seams. Here again the writer agrees with Professor Smyth that the facts are against the replacement theories as ordinarily advanced, especially since many layers of impervious rock lying in a more or less horizontal position intervene between the ore seams and the sur-

face. Yet the writer's own conception of the origin of these ores is much strengthened by these same conditions, which are indeed necessary, according to his ideas, for the existence of the iron-bearing seams. Because of these conclusions, it seems unnecessary to the writer to spend further time on a theory that in the light of such conditions as have been pointed out seems not only inadequate but impossible.

Secondary Enrichment Theories

Under the head of secondary enrichment may be classed both enrichment due to replacements and that due to residual enrichment. Of the theories of secondary origin, some depend upon leaching of soluble matter and a consequent enrichment of the iron-bearing deposits because of relative insolubility of the iron, and others upon a combination of replacement with enrichment by a process of leaching of iron from overlying ferruginous shales and slates and replacement of the lime in the underlying limestone by iron thus obtained. The most that can be said regarding these possibilities is that undoubtedly these alterations have been made, but to a very limited extent, and such methods are wholly inadequate to explain the distribution of the ore, as shown by recent borings and extensive underground mining, which have proved that hard ore does not change materially with depth, and that the above theories only account for the very superficial facies called soft ores. Absence of extensive exploration gave these theories plausibility and caused much favorable comment upon them for a time, but more recent underground mining has caused them to be more or less generally discredited.

Simple Replacement Theory

We still have one well recognized theory to discuss before advancing the theory of the writer, and that is simple replacement. The advocates of this theory have seen extensive evidence of replacement of the calcite by iron in the fossiliferous beds and have noted the replacement of the lime cement by iron. In respect to the evidence advanced by these authors, the writer is inclined to believe that to a large extent it is correct, but in a few particulars he finds himself obliged to disagree with their deductions.

The first is the attempt to account for the iron as a leached product from overlying shales. It seems incredible that such immense quantities of iron can have been derived from so limited a source. It also appears, as Professor Smyth has well stated, that the intervening layers of limestone which are comparatively free from iron would have offered

an excellent field for progressive replacement, whereas we find more or less clean-cut contacts and underlying rich iron ore beds. A second point of disagreement is in relation to the direction of movement of the iron-bearing solutions under these theories, which, in the various papers examined, seems to be by vertical descent of ground water, often limited in depth to a few hundred feet. Thus I. C. Russell (292) refers to a case in Attalla, Alabama, in which the ore changed to ferruginous limestone within a few hundred feet of the surface.

PART II. ARTESIAN REPLACEMENT THEORY

ARTESIAN CONDITIONS

CONTROLLING FACTORS

Artesian conditions result from a natural arrangement of strata in such manner that they act as a retaining basin or catch basin in porous strata in which water is or may be confined under hydrostatic pressure sufficient to cause the water to rise when the reservoir is tapped.

The conditions requisite for the existence of artesian wells, as set forth by Chamberlin (54a), are the following:

- 1) A porous stratum for the penetration of water;
- 2) An impervious underlying layer to prevent the downward escape of water;
- 3) An impervious overlying layer to retain the water under pressure;
- 4) An inclination of the layers, at least in part, so that the point of entrance is higher than any other portion of the retaining layers;
- 5) A reasonably large exposure of the porous layer, in order that free entrance may be provided for the penetrating waters;
- 6) Sufficient rainfall for water supply;
- 7) Absence of any place of escape for the retained water.

This summary of the usually quoted factors may be taken to indicate ideal artesian conditions, but many variations may exist and still allow artesian flow, although these requisites or adequate substitutes for them must be present.

The pervious medium may be any crystalline or sedimentary non-crystalline rock or stratum which contains enough pore space to permit a circulation of the penetrating water. Sandstones (particularly of coarse texture), fossiliferous limestones and even in some cases coarsely crystalline limestone may serve as a carrier and saturation medium for artesian waters. In some instances, even bedding planes, laminations or fracture systems may be adequate.

The impervious floor is not absolutely necessary. In some cases, artesian flow might be expected if the underlying layer, although penetrable, was less porous than the middle layer, so that the incoming water would accumulate with greater rapidity than it could escape downward. This would occur in the case of the two sandstones of marked difference in texture, the upper coarser and the lower finer.

The impervious layer above is more essential, but even here extreme differences of texture may give some results, even though the overlying layer is somewhat porous. It must be remembered, moreover, that porosity is relative and that absolutely impervious strata are unknown.

Another very important consideration with reference to these porous and impervious layers is the possibility of accumulations by precipitation or by the mechanical filling of voids at or near the line of contact between the strata. If, for example, two sandstones, one coarser than the other, are in contact, precipitation would first occur near the contact in the pore spaces of the finer textured rock, as there the penetrating solutions would move with less freedom and rapidity.

Mechanical sediments as well as mineral crusts might be expected to play some part toward establishing more complete artesian conditions.

Circulating ground waters, following lines of least resistance, tend to establish more or less definite channels, and if these channels are fairly well retained, nature itself will attempt to improve conditions by steadily increasing the density of the carrying medium through cementation and other processes of filling the minute channels of escape.

Inclination of artesian beds is necessary only for the purpose of allowing gravity to establish hydrostatic pressure. If the water head is sufficiently high to develop enough pressure to overcome the friction and other causes of retarding a free flow of water, it is fair to assume that artesian waterways may exist in practically horizontal layers, the movement of the water depending upon the amount of pressure exerted by the water column.

The absence of an avenue of escape may be accounted for in many ways; for example, a marine slope may be terminated at the lower end by a change of texture from coarse to very fine, as sand to mud; or precipitation may take place at the lower end of a runway, thus filling the voids in the previously porous layers.

CIRCULATION OF ARTESIAN WATERS

It has been suggested that artesian water is stagnant until tapped; but the writer is inclined to believe that absolutely stagnant artesian waters would be unusual if not impossible.

In the first place, any leakage, even though very slow, would promote circulation in the inclosed waters; artesian conditions depend upon relative, rather than absolute, imperviousness.

In the second place, differences in temperature would cause the establishment of currents involving a more or less constant circulation. That such differences of temperature do exist between the surface waters at the outcrop of the porous layers and the waters confined at considerable depths is hardly open to question. The density of cooler water is greater than of water at higher temperatures, and therefore such water would be acted upon by gravity, causing the denser water to sink while the less dense would rise.

In the third place, dissolved salts would add to density of the waters, and if solutions heavily charged with iron salts were admitted to the artesian runways, they would tend to sink until by precipitation they lost a part or most of their load, after which they would tend to rise and give place to other charged water from above.

Fourth, waters charged with insoluble mechanical sediment would tend to sink and set up circulation within the runway.

Fifth, oscillating movements of the water would occur because of tidal variations in load, accession of fresh surface water, crustal movements and other minor causes effecting changes of pressure transmitted in various ways, such as through the overlying impervious layer or through the water in the reservoir.

Slowly moving waters thus act as carriers of iron salts and other minerals and gases and precipitate much more readily because of relative confinement and slow method of circulation.

TYPICAL SECTIONS OF CLINTON ORES

MISSOURI

Holt County. Drill hole. Red oölitic hematite of Clinton age, 1,885 feet below surface, showed the following section (Crane, 66) :

	Feet	Inches
Purple shales (impervious).....	21	3
Oölitic hematite (porous).....	3	8
Earthy argillaceous hematite.....	..	5
Light green sandy shale (impervious).....	2	6
Bluish green shale (impervious).....	64	9

ALABAMA

In the Birmingham District, out of about 80 sections extending over forty-two properties, seventy-two included ore seams either fossil or

oölitic with shale or slate directly overlying and underlying the ore beds. These seams included the Ida, Big and Irondale, besides many too small to be of practical importance. (For sections, see Eckel, **37**, pp. 74–78.)

Section East No. 2 mine, Red Mountain (Phillips, **266**, p. 64) :

	Feet	Inches
Clay and soil.....	6	..
Sandstone	3	..
Clay	1
Sandstone	1	..
Clay	2
Ore	6
Clay	2
Ore	3.5
Clay	1
Ore	4
Clay	4
Ore	4
Clay	0.5
Ore	1	1
Clay	2
Ore	10
Clay	1
Ore	2.5
Clay	0.5
Ore	0.5
Clay	1
Ore	2
Clay	0.5
Ore, fine grained.....	..	2
Clay	2
Ore, fine grained.....	1	4
Slate	0.5
Ore, fine grained.....	..	5
Clay	1
Ore, fine grained.....	..	7
Slate	1
Ore, fine grained.....	..	4
Slate	2
Ore, sandy.....	..	1
Slate	1
Ore, sandy.....	..	2
Slate	1	..
Ore, sandy.....	..	6
Slate	1
Ore, sandy.....	..	7
Slate	1
Ore, limy.....	..	2
Slate	0.5
Ore, limy.....	..	2

	Feet	Inches
Slate	0.5
Ore, limy.....	..	8
Clay	0.5
Ore, sandy.....	..	6
Slate	3
Ore, sandy.....	..	3
Slate and sandy ore.....	..	6
Ore, sandy.....	..	1
Clay	0.5
Ore, sandy.....	..	3
Slate	1
Sandstone	6
Ore, good.....	10	..
Ore, poor.....	12	..

Cherokee County. Section at Ford New Bank, N. W. $\frac{1}{4}$ of N. W. $\frac{1}{4}$, Sec. 33, T. 9, R. 9 E., southwest side of Round Mountain (Phillips, 266, p. 42) :

	Feet	Inches
Shale, cover.....	..	..
Ore, soft, upper bench.....	..	6
Shale, ore.....	1	..
Shale, yellowish.....	1	6
Ore, reported to be 2 feet in places, lower bench.	1	2
Sandstone .....	..	..

Dekalb County. S. W. corner S. E. $\frac{1}{4}$, Sec. 4, T. 10, R. 6 E.:

	Feet	Inches
Shale .....	..	..
Ore, shaly.....	1	6
Shale	3	..
Ore	1	..
Shale .....	..	..

Same a little northeast:

	Feet	Inches
Shale
Ore, good.....	..	8
Shale	15	..
Ore	10
Shale

N. W. corner of Sec. 33, T. 8, R. 4 E. (266, p. 45) :

	Feet	Inches
Ore, about.....	4	8
Shale, about.....	18	..
Ore, about.....	..	4
Shale	10-12	..
Ore, about.....	..	3

For other sections adjacent to above, see 266, pp. 44-48.

Etowah County. Broughton Bridge Gap, N. E. $\frac{1}{4}$ of N. E. $\frac{1}{4}$, Sec. 7, T. 11, R. 6 E. (266, p. 48) :

	Feet	Inches
Sandstones with some interstratified shales and loam	225	..
Shale, ore, in alternate streaks.....	..	10
Sandstone, very hard, called cap rock to ore....	..	2
Shale .....	..	2
Ore .....	..	2
Shale .....	..	2
Ore	1	2
Shales with interstratified sandstone, about.....	100	..
Ore, good and soft, outcrop about.....	3	..
Shales, sandstones, about.....	175	..
Shales, ore, the ore very sandy and in thin seams in shale.....	10	..
Loam, sandy, red, with loose shales, about.....	80	..
Loam, ore, the ore sandy and in loose pieces in red sandy loam, about.....	10	..
Pelham (Trenton) limestones.....	..	..

Jefferson County. West Red Mountain. Section in Pit in S. E. $\frac{1}{4}$ of N. W. $\frac{1}{4}$, Sec. 20, T. 15, R. 1 W. (266, p. 52) :

	Feet	Inches
Debris, soil.....	..	..
Ore, sandy, in large grains.....	5	..
Shale, yellowish, only in places.....	..	1
Ore .....	..	2
Shale, yellowish.....	..	2-3
Ore	1	4
Shale, ore, the shale is yellowish and carries the ore only in places, in streaks.....	..	6
Ore	1	2
Shale, yellowish.....	12-14	..
Ore, soft, scarlet color.....	1	..
Ore, shale, in alternate streaks, the ore is sandy	1	..
Ore, shale, the ore is soft.....	7	..

Section of Big Seam, opposite Oxmoor (266, p. 61) :

	Feet	Inches
Ore	7	3
Shales, pebbles.....	Trace	..
Ore	8	..
Shales .....	..	3
Ore	2	3.5
Shale .....	..	.75
Ore	8	2
Shale .....	..	1.25
Ore	1	2.5

	Feet	Inches
Shale .....	..	2
Ore .....	..	11
Shale	7	..
Ore	1	3

GEORGIA

In Georgia, the same arrangement of strata prevails as that found in Alabama. The porous layers of sandstone or limestone are joined top and bottom with impervious layers of slates or shales. In a few cases, fine-textured sandstone joined the much coarser layers of ore. Thirty-seven sections taken in this state showed without exception similar favorable artesian conditions. In nearly all cases, the ore seams consisted of fossil ore and always much coarser than surrounding layers.

Walker County, Lookout Mountain (216, p. 96), Edmund Evitt's property. Lot 220, 12th district:

	Feet	Inches
Shale .....	..	..
Ore	2	..
Shale	4	..
Ore .....	..	10
Shale .....	..	..

Chattooga County. Lookout Mountain (216, p. 123). W. T. Henry's property. Lot 171, 13th district:

	Feet	Inches
Shale .....	..	..
Ore	1	2
Shale	1	10
Ore .....	..	4
Shale .....	..	6
Ore .....	..	2
Shale .....	..	..

Dirtseller Mountain. Z (216, p. 130). Lot 150, 14th district:

	Feet	Inches
Decomposed shale and surface clay.....	9	..
Ore	4
Shale	4
Ore	2.5
Shale	1
Ore	1
Shale	2
Ore	3
Shale	1
Ore	6
Sandstone (heavy beds).....

Taylor's Ridge (216, p. 133) :

	Feet	Inches
Heavy-bedded sandstone.....
Ore	5
Shale	1
Ore	1	1
Shale

Mr. Maddox's property (216, p. 135). Lot 160:

	Feet	Inches
Sandstone .....	..	..
Ore .....	..	7.5
Shale .....	..	3
Ore	1	1.5
Shale	7	..

Dade County. Lookout Creek (216, p. 59). Lot 83, 18th district:

	Feet	Inches
Ore (overlain by shale).....	..	10
Shale .....	..	8
Ore	1	..
Shale .....	..	1
Ore .....	..	6
Shale .....	..	3
Ore .....	..	6
Shale .....	..	1
Ore	1	..
Shale	2	..
Ferruginous, fossil limestone.....	..	9
Shale	6.5	..
Fossiliferous limestone.....	..	4
Shale with thin layers of sandstone and lime- stone	40	..

TENNESSEE

Safford (295, p. 304) :

	Feet	Inches
Greenish shale.....	22	..
Ore, with parting of shale.....	1	6
Sandstone, fine grained.....	6	..
Greenish shale with occasional iron seams.....	67	..
Oölitic ore, calcareous.....	4	..
Greenish shale.....	21	..

VIRGINIA

Low Moor, Horse Mountain (92, p. 188) :

	Feet	Inches
Slates and thin sandstone.....	..	10
Fossil ore, brown and porous.....	..	7
Fossil ore, red and fairly good.....	1	2
Ochery clay.....	..	6
Shales	2	..

Slope 2 :

	Feet	Inches
White quartzite.....	30	..
Shales .....	..	2
Red fossil ore.....	1	4
Ochery shales and thin sandstone.....	1	..
Shales and sandstone.....	2	..

Big Stone Gap, Va.:

	Feet	Inches
Slate, badly weathered.....	1	..
Oölitic ore.....	..	8
Slate .....	..	..

WEST VIRGINIA

In West Virginia, the same artesian arrangement of strata prevails as that found in the more southern states. Shales overlying and underlying ore seams in almost all cases.

Pendleton County. Wagner Knob (130, p. 166) :

	Inches
Hanging wall, green shale.....	..
Good ore.....	5
Dirt and clay.....	4
Sandy ore.....	18
Foot wall.....	..
Foot wall, green shale.....	..

Z (130, p. 167) :

	Inches
Hanging wall, green shale.....	....
Good ore.....	6.5-9
Green shales.....	7.5
Good ore.....	3-4
Slaty ore.....	4
Green shales.....	9
Slaty and sandy ore.....	5-6
Foot wall, green shale.....	....

(130, p. 197) :

	Feet	Inches
Black shales.....	4	..
Red fossil hematite.....	1	..
Thin, flaky, black shale.....	..	4
Limestone .....	..	2
Shales with lime layers.....	1	..

PENNSYLVANIA

The same arrangement of ore and shale is found very generally in Pennsylvania.

Union and Snyder Counties (84, pp. 65-68) :

	Feet	Inches
Sandy calcareous shales.....	175	..
Ore, sand vein.....	2-3	..
Purplish red calcareous shale.....	10-30	..
Ore, Danville ore.....	..	16-18
Shale, middle olive shale.....	150	..
Iron sandstone and shales.....	60-70	..
Shale, lower olive shale.....	500-600	..
Birdseye fossil ore.....	..	8-10
Shales, lower olive shales.....	150	..

Moore's Ore Bank (83, p. 58.F) :

Shale	White clay, carbonaceous
Ore	Limestone, at top a rotten olive shale
Fire-clay	Sandstone
Ore	.

Granville Gap (83, p. 46 F) :

	Feet	Inches
Lower Clinton shales.....	135	..
Block-ore	13	..
Ferruginous sandstone.....	6	..
Shale, light green and yellow.....	30	..
Birdseye fossil ore, rich.....	..	8-12
Yellow shale.....	30	..
Block-shot-ore .....	..	..
Shales	150-200	..
Medina sandstone, No. IV.....	..	..

NEW YORK

The Clinton red hematites of New York meet the requirements of the artesian theory: impervious layers of shales and cherty limestones, with coarse oölitic or fossil ore in the porous layers.

Genesee Gorge, Rochester (234, p. 20) :

	Feet	Inches
Bluish gray limestone.....	18	..
Green shale.....	24	..
Hard siliceous limestone.....	14	..
Iron ore, fossil.....	..	14-16
Green shale.....	24	..

Ontario (234, p. 21) :

	Feet	Inches
Cherty limestone.....	8	..
Iron ore, fossil.....	2	2
Green shale.....	9	..
Medina shale.....	..	..,

Clinton (317 and 216, p. 29) :

	Feet	Inches
Sandstone, calcareous, thin shale at bottom.....	50	..
Red flux bed, shale partings.....	6	..
Sandstone, very calcareous, with small seams of iron	6	..
Shale	15	..
Oölitic ore.....	..	25-40
Shale, merely a parting.....	2	..
Oölitic ore.....	1	..
Shale, with some sandstone.....	100	..

NOVA SCOTIA

The same artesian strata are found in Nova Scotia. It is uncertain that these ores are Clinton, but they are called Clinton by several writers, and until they are more accurately placed, they will be referred to as Clinton ores.

Baker No. 1, Pit 10 (South Side) (356, p. 71) :

	Feet	Inches
Ore .....	..	10
Slate	2	10
Ore .....	..	4
Slate	2	6
Ore .....	..	7
Slate	1	6
Ore	2	3
Slate	3	3
Ore .....	..	6

Leekie Vein, Pit No. 24 (356, p. 80) :

	Feet	Inches
Green soft slate.....	1	..
Ore	1	..
Slate	1	3
Ore .....	..	6
Green soft slate.....	..	..

ARTESIAN CONDITIONS IN THE CLINTON DEPOSITS

A close examination of a hundred or more ore seams, distributed from Birmingham, Alabama, to Rochester, New York, has been made by the writer, and in practically every case structures were found that would favor excellent artesian conditions. Beside the seams personally examined, practically all available literature that contained sections of Clinton deposits (and including some unpublished manuscripts also containing sections) has been carefully examined, with the same result in nearly every case. Out of more than eighty sections in Alabama alone, seventy-

two showed ore seams with shale or clay partings or strata ranging from a fraction of an inch to several hundred feet in thickness above and below.

Taking up the artesian conditions found in the Clinton iron ore deposits more in detail, we find governing factors.

POROUS LAYERS

The first are the porous strata, or better those which were without doubt originally porous, and which consist of fragmentary rocks such as sandstones now in many cases altered to the oölitic hematite beds. Seams of this class were personally examined at Clinton, New York, and Big Stone Gap, Virginia. Specimens of oölitic ore with quartz grains as nuclei were also examined from Kentucky and from Wisconsin. Records of similar strata have been found in Ohio and West Virginia.

Rock slides made from this class of ore show conclusively that the original sediments must have been ordinary shore or near-shore deposits of sand, similar in every way to ordinary marine sand such as we find on our beaches to-day. Sand, loose or consolidated by cementation into common sandstone, forms as perfect a porous medium as could be desired for artesian purposes. Some sandstones show as high as 30 per cent pore space. The other principal type of Clinton ore, the fossil ore, consists of beds of fossil fragments such as pieces of crinoid stems, corals, bryozoans, brachiopods, and many other varieties of Clinton fossils, deposited by the ordinary processes of sedimentation and later consolidated into the usual types of fossiliferous limestones. These furnish, in the earlier stages at least, ideal porous conditions and are quoted by practically all writers on artesian flows as favorable for water penetration.

After a close examination of slides of these fossil beds (Plates IX, XVI), it cannot be doubted that for a time at least these layers must have been extremely free runways for penetrating surface waters. Artesian reservoirs exist in rocks like the coarsely crystalline limestones, far less favorable than either sandstone or fossiliferous limestone, and therefore it would appear to the writer that the complete porosity of these layers can hardly be disputed.

IMPERVIOUS LAYERS

Impervious contacts were found, separating two strata of different textures and degrees of porosity.

As has already been pointed out (page 138), where two porous layers

of different density occur together, there seems to be a natural tendency for either mechanical or chemical filling to take place, beginning along the line of contact and extending a short distance into the finer-textured stratum, thus protecting the latter from further penetration by the solutions contained in the coarser layer as effectually as though the finer layer had been impervious in the first place. This is well shown in various specimens of cavernous consolidation (Plate XI), in which iron solutions penetrated the finer sand for a short distance, filling the pore spaces so completely that part of the inclosed sand remained not only uncoated with iron, but even unconsolidated.

MARINE ARTESIAN SLOPES

Marine artesian slopes are among the common sources of artesian water supply to-day. Strata of alternating sand and mud, often many times repeated, are among the commonest types of in-shore deposits, and these sedimentary layers as originally deposited have an initial dip. Furthermore, the coarser and more porous layers as they extend into deeper waters tend to change their textures from coarse to fine and their contents eventually from sand to mud or ooze. These conditions result in a natural catch basin for penetrating water that cannot be improved upon for the establishment of good artesian conditions.

The Clinton beds comprised alternating impervious and porous layers, forming the marine slopes of the epicontinental shelf of that period, a condition in all respects favorable for the retention of artesian waters after uplift. These runways probably were brought to an end downward by a change of texture and material from porous to impervious deposits seaward; but even if such a sealing of the porous medium did not occur, it is highly probable that in a comparatively short time precipitation would cause a filling of the voids at the lower end of the runways and accomplish the same results as a change of texture.

INFILTRATION OF METEORIC WATER

That conditions favorable to the easy penetration and retention of ground or surface waters could exist, therefore, seems clear; and that penetration of such water in these channels took place is equally well indicated by field study and the microscopic examination of slides from Clinton seams. This is shown by the evident and widespread corrosion of the nuclei of calcite (Plates IX, XVI), and even quartz in some cases (Plates XX, XXI), that form so large a part of these deposits. If we

admit that these fragments and grains are corroded, we must also admit that solvent waters were present at some time in these artesian runways.

We are not dependent, however, upon this one bit of evidence. The penetration of iron for short distances into slightly porous contact layers, with a progressive thinning out of the iron (Plate XX, fig. 2), until within a short distance from the line of contact penetration and precipitation altogether ceased; the filling of the seams caused by cross-bedding, mudcracks (Plate XVIII), sand streaks in the shale, fractures and places of weakness, all point to precipitation from penetrating solutions. Cavernous consolidation in loose sand layers (Plates XI, XII, XIII), filling of corrosion embayments in nuclei (Plates XVI, XX, XXI), widespread replacement in all stages of completeness of calcite and in some cases of quartz by iron, and the secondary calcite, iron and to some extent silica cementation of the iron-coated fragments, all add to the certainty of the filling of these retaining layers or catch basins with artesian waters.

Thus we must conclude that all the factors necessary for complete artesian conditions existed in the Clinton strata; that much evidence has been adduced that these natural artesian runways were well filled with ferruginous solutions, and finally that these solutions were responsible for the present mineral content of the ore seams.

ORE CONDITIONS RESULTING FROM ARTESIAN SLOPES

DEPTH OF DEPOSITS

The only downward limit under this theory would be the limit of the artesian flow. As artesian wells have been sunk in some cases to more than 4,000 feet, and as artesian conditions would seem to be as perfect in the Clinton strata as could be expected anywhere, it appears to the writer at least that the only limit of ore deposition would be the seaward extremity of the porous strata, and that this limit might well be expected in many places to extend to at least as great depths as any artesian well known at the present time.

That borings in Birmingham, Alabama, have demonstrated the existence of good ore at 1,902 feet would appear to bear out the writer's contention that the iron content of the seams should extend to great depths with little or no change in richness within the hard-ore limits and that this condition would be found wherever the proper artesian factors along the marine slopes existed. In Holt County, Missouri, a borehole 1,885 feet showed good ore at that depth and favorable artesian conditions because of the impervious overlying and underlying beds (66, p. 148).

EXTENT OF DEPOSITS DOWN THE DIP

Some artesian flows are found to extend for more than a hundred miles from the outcrop, and flows tapped scores of miles from the intake are not uncommon. If we admit that artesian conditions are responsible for the existence of these ore deposits, then we must recognize that the limit of artesian layers alone will determine the distance along the dip to which these deposits can be expected to extend. As one fairly good example, the case noted by Newland (234, p. 51) might be cited:

"The recent exploration with the diamond drill has shown that there is no notable change of character on the dip for distances of five or six miles from the outcrop. Deep borings made some years since at Syracuse and Chittenango found hematite below 600 feet, showing it to be of normal composition."

WIDE DISTRIBUTION OF DEPOSITS

Conditions that caused the formation of artesian runways, and later conditions that brought about periods of heavy rainfall and rapid weathering sufficient to produce the iron-bearing solutions that penetrated and filled with iron ore these artesian runways or reservoirs, were so widespread and extensive that no merely local results could follow, but rather the development of a series of artesian slopes such as we find along the whole Silurian shoreline, well filled with ferruginous material.

OCCURRENCE OF OÖLITIC AND FOSSIL ORES

Whether the porous layers were limestone or sandstone would not affect the question of genesis in any way, under this theory. Sandstone strata might produce oölitic hematite, while fossiliferous limestone might produce the characteristic fossil ore, and still both types were dependent upon similar artesian runways and penetrating iron-bearing solutions.

VARIATIONS IN CHEMICAL COMPOSITION

As these Clinton ores extend nearly two thousand miles along the outcrops, and as the old land areas varied in composition, in some places containing acid rocks and in others basic with different mineral constituents, a difference in chemical composition of the ores might be expected. The fact, also, that the porous layers differed to some extent, some possibly having a primary silica cement, others a calcareous cement, and still others having no cement whatever, these and other minor variations in the original deposits would lead one to expect just such variations in composition as we find in ore beds to-day. It would, therefore, still

further tend to strengthen the artesian theory that such variations in mineral content exist.

VARIATIONS IN TEXTURE

Variations in texture would be inevitable, exactly as they occur to-day in any series of marine shore deposits, and the texture of the different ore seams varies as would be expected, seams of fine ore and seams of coarse in the same localities being found, and also variations within the same seams.

VARIATIONS IN RICHNESS

Artesian conditions would also account to a large extent for the variations in richness of the Clinton ores of different localities and for variations within the same seam. Differences in temperature, pressure, rate of flow and size, shape and composition of the grains of sand within the porous layers would all influence the degree of richness of the ore, as would variations in the nature of the cement.

Artesian replacement, therefore, would account satisfactorily for depth, extent along the dip and wide distribution of the ore deposits. It would apply equally well to the fossil ores or to the oölitic hematites, and it would satisfactorily explain the variations in composition, texture and richness.

On the other hand, the absence of artesian conditions would account for a deficiency or total absence of iron in limestone or sandstone strata otherwise favorably located. In Niagara Gorge, where the Clinton strata are well exposed, no ore seams outcrop. Otherwise, unaccountable breaks in the continuity of the ore deposits could easily be explained by a failure of the strata to provide good artesian runways or catch basins for the iron-bearing solutions.

ARTESIAN REPLACEMENT THEORY AS APPLIED TO OTHER HORIZONS

It is not likely that conditions favorable for the accumulation of iron ore in the porous strata of artesian runways will be found in any other geological horizon on such an extensive scale as those of the Clinton. The peculiarly favorable conditions resulting from the rapidly changing textures of sedimentary beds deposited in the Silurian Sea, and the periods of crustal movements, heavy precipitation and rapid weathering which followed, furnished a most remarkable combination of factors requisite for the formation of great numbers of artesian runways, with ample opportunity for subsequent filling. It is to be expected, however, that artesian conditions will be found in many horizons of marine strata at

widely different ages. If these artesian runways have been so situated that mineral-bearing solutions could penetrate their porous layers, there is no reason why deposits similar to those of the Clinton age should not be formed.

The exact stratigraphic position of several of the so-called Clinton beds is uncertain, and when the fossil content of these beds has been worked out, some changes may be expected in their stratigraphic position. The geologic position of some of the interbedded hematites and magnetites of Nova Scotia, which by some have been classed as Clinton, is still in doubt.

The writer has used the term Clinton more to characterize a type of deposit than the ore from a definite geologic horizon, and it is probable that several beds referred to as of Clinton are not of Clinton age. It is certain, however, that all the occurrences treated in this paper are well within the Paleozoic.

DEPOSITS OF WABANA, BELLE ISLE, NEWFOUNDLAND

The Wabana deposits of Newfoundland would appear to meet the requirements of the artesian theory fully as well as the beds already referred to under the Clinton. The porous layers now represented by the ore beds, the impervious or less porous adjoining layers giving good artesian runways, the marine slope giving the proper inclination to the beds and the necessary limit of the porous layers by marine slope methods, and finally the great depth and continued richness of the deposits, all point toward artesian replacement.

DEPOSITS OF THE MIRA VALLEY, CAPE BRETON, N. S.

The Cambrian ores of the Mira Valley, Cape Breton, also have the necessary factors of artesian ore deposits. The iron ores occur in limestones and quartzites as the porous layers with slates interstratified, thus giving the same general conditions as were noted in the usual type of Clinton deposit.

Study of other deposits indicates that although this theory is more extensively applicable to the Clinton ores, it is equally applicable to similar beds of iron ore in other horizons and may be found useful in working out the origin not only of other iron ores but other minerals as well.

GENERAL SUMMARY AND CONCLUSIONS

The advocates of the sedimentary theory, although advancing many plausible arguments in favor of their ideas of origin of the Clinton ores,

yet depend upon a condition of ore deposition unknown at any other time, the direct precipitation of iron ores in sea-water. Posepny says (273, p. 121)

"In short, a number of investigators have adopted the hypothesis of an original deposition from the ocean without giving any other reason than the observed relations of stratification. Yet, in a considerable experience with ore-deposits in marine limestones, I have never been able to find genuine ore-beds among them, but always only ores of subsequent introduction; so that I feel warranted in believing that such beds proper *do not exist*."

They recognize many factors that are difficult to explain under their hypothesis. Many conditions are found that cannot be accounted for under this theory. Moreover, the principal points in favor of the sedimentary theory apply equally well to the Artesian Replacement Theory. The field conditions, hard to account for under the sedimentary hypothesis, are expectable under the latter theory. Instead of relying upon conditions unknown before or since, the writer bases his deductions only upon well recognized conditions that are known to have been in operation during many geological periods.

The writer has therefore come to the following conclusions in regard to the origin of most of the Paleozoic interbedded iron-ore deposits:

- 1) The Clinton strata were favorable for the deep penetration of surface water along well defined runways of porous rock, protected top and bottom by impervious strata.

- 2) Iron-bearing solutions actually did penetrate these artesian slopes and were to a large extent responsible for the deposition of the Clinton hematites and other interbedded iron-ore deposits.

- 3) The strata were evidently marine but chiefly of a near-shore type, as shown by shallow-water conditions such as the accumulation of large deposits of fossil fragments, evidently broken to pieces by the action of shore waves and ocean currents.

- 4) Corals were found in sufficient number to indicate that conditions necessary for successful growth of the polyp, such as mild climate, shallow water, open sea and a lack of much fresh water, must have existed.

As the beds were marine, shore or near shore deposits, they must have been formed with a gentle seaward dip.

The Silurian Sea produced all of the conditions necessary for artesian slopes.

After these strata were formed, elevation took place, so that the outcrops were above the sea and the porous layers were then in a position to receive surface water. Then came a period, or possibly several periods, of considerable precipitation and abundant weathering; large volumes of

iron-bearing waters, deriving the necessary solutions from the old granitoid and schistose rocks, found their way down these natural runways. The water probably contained considerable carbon dioxide (CO_2) and thus, because of its own nature, aided by increasing pressures and temperatures, became an active solvent, until it reached the saturation point; it then became a depositional agent and began to deposit. The iron salts were probably the first ingredients to be given up; then followed other constituents, such as secondary calcite and silica which form a prominent part of the final deposits.

The solid particles which were not entirely dissolved from the original constituents of the porous layers, and which included in many cases large numbers of quartz grains, became centers for the segregation of iron. These quartz grains were therefore first corroded to a varying extent and then protected from further corrosion by layers of iron and in some cases secondary silica. Finally, the remaining pore space was filled in by secondary calcite, sometimes mixed with iron. In a large number of cases, the iron replaced both calcite and quartz. This is well shown where the iron has worked its way into microscopic cracks and gradually clouded the quartz and other nuclei and in many cases actually replaced it.

The artesian contacts are fairly clean, as would be expected, the shales and clays furnishing the cleanest of the contacts except those forming along fractures. Where such breaks occur in the inclosing layers, they are filled with streaks of iron ore. The iron appears to follow fractures and other such planes of weakness as lamination or stratification planes. Iron also fills mud cracks and other holes and porous places left in the shales and other contact layers.

Where iron has penetrated a short distance into the inclosing layers, it appears as though much pressure had been exerted upon the solutions.

Depth, extent along the dip, wide distribution, differences in composition, texture and richness, all can be accounted for under this theory without the necessity of appealing to special conditions, unique for this particular period. Under the artesian theory, deposits were probably made with the usual deliberateness characteristic of natural processes of deposition. It is entirely possible that the time consumed in the complete filling of these artesian runways with ore was many times longer than the time taken for the deposition of the sediments that composed the original Clinton layers.

Finally, under the Artesian Replacement Theory, the genesis of the iron ores shows an interesting similarity in many ways to that of origin of the Lake Superior hematites and magnetites.

PART III. BIBLIOGRAPHY

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PLATE VII

**MAP SHOWING THE DISTRIBUTION OF CLINTON HERMITES IN THE UNITED STATES
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VOLUME XXIV, PLATE VII

PLATE VIII

FOSSIL ORE

FIG. 1.—Specimen 1. Chattanooga, Tenn.

FIG. 2.—Specimen 2. Attalla, Ala.

PLATE VIII

FOSSIL ORE

FIG. 1.—Specimen 1. Chattanooga, Tenn.

FIG. 2.—Specimen 2. Attalla, Ala.

FIGURE 1

FIGURE 2

PLATE IX

FOSSIL ORE—PHOTOMICROGRAPHS

FIG. 1.—Microscopic slide of medium-textured ore from Clinton, N. Y.

FIG. 2.—Same slide. Note porosity.

FIG. 3.—Slide from Clinton, N. Y. Note character of quartz nucleus.

FIG. 4.—Same slide. Note iron segregation.

FIG. 5.—Calcite granules replaced by iron. Chattanooga, Tenn.

FIG. 6.—Slides from Clinton, N. Y. Note replacement by iron as in Fig. 5.

PLATE IX

FOSSIL LIFE - PHOTOMICROGRAPHS

- Fig. 1.—Microscopic slide of medium-textured ore from Clinton, N. Y.
Fig. 2.—Same slide. Note porosity.
Fig. 3.—Slide from Clinton, N. Y. Note character of quartz inclusions.
Fig. 4.—Same slide. Note iron concretions.
Fig. 5.—(a) Same slides replaced by iron. (b) Same slide. Iron.
Fig. 6.—Slide from Clinton, N. Y. Note replacement by iron as in Fig. 5.

PLATE X

OÖLITIC ORE

FIG. 1.—Specimen 3. Loose oölitcs. Clinton, N. Y.

FIG. 2.—Specimen 4 and Specimen 5. Oölitic ore from Big Stone Gap, Va.

PLATE X

COINTE ORE

Fig. 1.—Specimen 2. (Lower right) (London, 2. 1.)

Fig. 2.—Specimen 4 and specimen 5. (Upper left from Plate 9.)



FIGURE 1

FIGURE 2

PLATE XI

CAVERNOUS CONSOLIDATION

FIG. 1.—Specimen 6. Big Stone Gap, Va.

FIG. 2.—Specimen 7. Loose quartz sand from cavity in Specimen 5.

PLATE XI

(AVERNOZ'S CONSOLIDATION)

Fig. 1.—Specimen 6. Big Stone (shp. 78).
Fig. 2.—Specimen 7. Loose quartz sand from cavity in Specimen 6.

FIGURE 1

FIGURE 2

PLATE XII

SPECIAL CONSOLIDATIONS

**FIG. 1.—Iron consolidation inclosing consolidation without iron. Specimen 8.
Big Stone Gap, Va.**

FIG. 2.—Specimen 9. Similar to Specimen 7. Same ore seam.

PLATE XII

SPECIAL CONSOLIDATIONS

- Fig. 1.—Iron consolidation including consolidation without iron. Specimen 6.
Big Stone Gap, Va.
Fig. 2.—Specimen 8. Similar to Specimen 1. Same ore seam.

FIGURE 1

FIGURE 2

PLATE XIII

SPECIAL CONSOLIDATIONS

FIG. 1.-- Specimen 8. Magnified.

FIG. 2.-- Specimen 9. Magnified. Note poor space.

PLATE XIII

SPECIAL CONSOLIDATIONS

Fig. 1.—Specimen 8. Magnified.

Fig. 2.—Specimen 8. Magnified. Note poor space.

FIGURE 1

FIGURE 2



PLATE XIV

•

F

F

PLATE XIV

PARTIAL IMPREGNATION

Fig. 1.—Specimen 10. Pebble in ore. Ontario, N. Y.

Fig. 2.—Specimen 11. Conglomerate ore from Big Seam. Birmingham, Ala.

.

FIGURE 1

FIGURE 2

PLATE XV

CHERTY LIMESTONE SEAMS

FIG. 1.—Specimen 12. Ontario, N. Y.

FIG. 2.—Specimen 13. Attalla, Ga.

PLATE XV

CHERRY LIMESTONE SEAMS

Fig. 1--Specimen 12. (Oriskany, N. Y.)

Fig. 2--Specimen 13. (Attitash, Me.)

.



FIGURE 1

FIGURE 2

PLATE XVI

FOSSIL ORE—PHOTOMICROGRAPHS

Fig. 1.—Slide from Attalla, Ala., showing cloudy replacement of quartz by iron.

Fig. 2.—Tongue of iron penetrating a calcite grain. Ontario, N. Y.

PLATE XVI

FOSSIL ORE—PHOTOMICROGRAPHS

FIG. 1.—Slide from Attalla, Ala., showing cloudy replacement of quartz by iron.

FIG. 2.—Tongue of iron penetrating a calcite grain. Ontario, N. Y.

FIGURE 1

FIGURE 2

PLATE XVII

CONTACT SPECIMENS

FIG. 1.—Specimen 14. Ontario, N. Y.

FIG. 2.—Specimen 15. Big Stone Gap, Va.

PLATE XVII

CONTACT SPECIMENS

- Fig. 2.—Specimen 12. Big Stone Gap, Va.**
Fig. 1.—Specimen 14. Ontario, N. Y.

FIGURE 1

FIGURE 2

PLATE XVIII

MUD CRACKS

FIG. 1.—Specimen 16. Clinton, N. Y.

FIG. 2.—Specimen 17. Helen Bess Mine, Birmingham, Ala.

PLATE XVII

MUD CRACKS

- Fig. 1.—Specimen 16. Clinton, N. Y.
Fig. 2.—Specimen 17. Helen Ross Mine, Birmingham, Ala.

FIGURE 1

FIGURE 2

PLATE XIX

CONTACT SPECIMENS

FIG. 1.—Specimen 18. Borst Mine, Clinton, N. Y.

FIG. 2.—Specimen 18. Magnified.

PLATE XIX

CONTACT SPECIMENS

Fig. 1.—Specimen 18. Borst Mine, Clinton, N. Y.

Fig. 2.—Specimen 18. Magnified.



FIGURE 1

FIGURE 2

PLATE XX

CONTACT SPECIMENS

FIG. 1.—Specimen 19. Clinton, N. Y. Ore seam between shale partings.

FIG. 2.—Photomicrograph of same ore as Specimen 19, showing contact.

OÖLITIC ORE—PHOTOMICROGRAPHS

FIG. 3.—Thick segregation of iron about quartz nucleus. Clinton, N. Y.

FIG. 4.—Penetration of quartz nucleus by iron. Clinton, N. Y.

FIG. 5.—Peculiar corrosion of quartz nucleus. Clinton, N. Y.

FIG. 6.—Corrosion and replacement of quartz nucleus. Clinton, N. Y.

PLATE XX

CONTACT SPECIMENS

Fig. 1.—Specimen 18, Clinton, N. Y. Ore seam between shale partings.

Fig. 2.—Photomicrograph of same ore as specimen 18, showing contact.

IGLITE OR PHOTOGRAPH

Fig. 3.—Thick section of iron about quartz nucleus. Clinton, N. Y.

Fig. 4.—Penetration of quartz nucleus by iron. Clinton, N. Y.

Fig. 5.—Perillar corrosion of quartz nucleus. Clinton, N. Y.

Fig. 6.—Corrosion and replacement of quartz nucleus. Clinton, N. Y.

PLATE XXI

OÖLITIC ORE—PHOTOMICROGRAPHS

FIG. 1.—Almost complete replacement of quartz. Clinton, N. Y.

FIG. 2.—Note corrosion and thickness of iron coating of nucleus. Kirkland Bed, Clinton, N. Y.

FIG. 3.—Penetration of iron in small fractures in quartz nucleus. Alabama ore.

FIG. 4.—Partial replacement of calcite with iron. Alabama ore.

FIG. 5.—Segregation of iron about quartz nucleus. Note replacement. Clinton, N. Y.

FIG. 6.—Nucleus partially replaced by iron carbonate (?) and then coated with iron-hydroxide. Kirkland Bed, Clinton, N. Y.

PLATE XXI

ÖÖLITIC ORE - PHOTOMICROGRAPHS

Fig. 1.—Almost complete replacement of quartz. Clinton, N. Y.

Fig. 2.—Note corrosion and thickness of iron coating of nucleus. Kirkland Red, Clinton, N. Y.

Fig. 3.—Penetration of iron in small fractures in quartz nucleus. Alabama ore.

Fig. 4.—Initial replacement of calcite with iron. Alabama ore.

Fig. 5.—Segregation of iron about quartz nucleus. Note replacement. Clinton, N. Y.

Fig. 6.—Nucleus partially replaced by iron carbonate (?) and then coated with iron-hydroxide. Kirkland Red, Clinton, N. Y.

ANNALS N. Y. ACAD. SCI.

VOLUME XXIV, PLATE XXI

CLIMATE AND EVOLUTION¹

BY W. D. MATTHEW

(Presented in abstract before the Academy, 13 February, 1911)

CONTENTS

	Page
Thesis.....	172
Introduction.....	173
Alternations of elevation and climate during geological time.....	173
Permanency of the ocean basins.....	174
Distribution of land and water, present and past.....	175
Effects of alternations of elevation and climate upon evolution of terrestrial faunas.....	176
Comparison with the paleontological record.....	178
Interpretation of supposed exceptions.....	179
Principles of dispersal.....	180
Review of the evolution of vertebrate life.....	181
Imperfection of the geological record.....	183
Zoölogical regions, past and present.....	185
Former barriers and bridges.....	189
Regional correlation.....	191
Synchronism and homotaxis.....	192
Tertiary correlation in South America.....	195
Centers of dispersal.....	200
Oceanic and continental islands.....	202
Faunal differences between oceanic and continental islands.....	202
Natural rafts and the probabilities of over-sea migration thereby....	206
Considerations affecting probabilities of over-sea migration in special cases.....	208
Dispersal of mammalia.....	209
Mankind.....	209
Primates.....	214
Carnivora.....	217
Canidæ.....	218
Procyonidæ.....	220
Mustelidæ.....	221
Ursidæ.....	221
Viverridæ.....	222
Hyænidæ.....	223
Felidæ.....	223
Pinnipedia.....	223
Insectivora.....	224
Chiroptera.....	227
Rodentia.....	228

¹ Manuscript received by the Editor, 20 October, 1914.

	Page
Perissodactyla.....	234
Equidæ.....	235
Tapiridæ.....	238
Rhinocerotidæ.....	240
Artiodactyla.....	241
Pigs and peccaries.....	241
Ruminants.....	242
Proboscidea.....	254
Sirenia.....	256
Condylarthra and specialized successors.....	257
Edentata.....	259
Marsupialia.....	262
Monotremata.....	270
Summary of the evidence from dispersal of land mammals.....	270
Interpretation of negative evidence in fossil mammal faunæ.....	273
Dispersal of reptilia.....	274
Dinosauria.....	275
Chelonia.....	280
Crocodilia.....	284
Lacertilia.....	288
Dispersal of birds.....	292
Dispersal of amphibia.....	294
Dispersal of fresh-water fishes.....	297
General considerations on the distribution of invertebrates and plants....	299
Interpretation of distribution data of crayfish.....	301
Distribution of <i>Helix hortensis</i>	303
Distribution of Percidæ.....	304
Criticism of some opposing hypotheses.....	305
On vain speculations.....	306
Summary of evidence.....	308
Appendix.....	311

THESIS

1. Secular climatic change has been an important factor in the evolution of land vertebrates and the principal known cause of their present distribution.

2. The principal lines of migration in later geological epochs have been radial from Holarctic centers of dispersal.

3. The geographic changes required to explain the present distribution of land vertebrates are not extensive and for the most part do not affect the permanence of the oceans as defined by the continental shelf.

4. The theories of alternations of moist and uniform with arid and zonal climates, as elaborated by Chamberlin, are in exact accord with the course of evolution of land vertebrates, when interpreted with due allowance for the probable gaps in the record.

5. The numerous hypothetical land bridges in temperate tropical and southern regions, connecting continents now separated by deep oceans, which have been advocated by various authors, are improbable and unnecessary to explain geographic distribution. On the contrary, the known facts point distinctly to a general permanency of continental outlines during the later epochs of geologic time, provided that due allowance be made for the known or probable gaps in our knowledge.

INTRODUCTION

ALTERNATIONS OF ELEVATION AND CLIMATE DURING GEOLOGICAL TIME

Several years ago,² I had the honor to give a talk upon "Climate and Evolution" before the Linnæan Society. The subject was then new to me—it was an application to vertebrate paleontology of theories in regard to geological history which had been brought forward by Chamberlin a year or two previously.³ I have had these concepts more or less in mind ever since, and though I must admit that I am far from having the evidence in shape for final presentation, I desire to submit for general consideration the conclusions thus far reached.

✓ Chamberlin's theories are to-day well known and are year by year gaining a wider acceptance. So far as they pertain to the present subject, they differ from the older prevailing concept of geological climatic conditions chiefly in that they involve an alternation of climates through the course of geologic time from extremes of warm, moist tropical and uniform, to extremes of cold, arid zonal climates. The former are the results of prolonged base-level erosion and the overflow of large continental areas by shallow seas. The latter are the results of the re-adjustments needed to bring the continents once more into isostatic balance, involving the general lifting of the continents, especially of their borders, the expansion of the continental areas to their utmost limits and the renewal of rapid erosion.

These alternations of conditions are marked by alternations of the prevalent type of formation in the geological series. The uniform base-leveling corresponds to widespread deposits of limestones and in its waning stages with coal formations. The periods of uplift are marked by thick barren formations, often red in color, by indications of arid conditions in salt and gypsum beds and they finally culminate in great extension of glaciers from boreal and high mountain areas. ↘

² Jan. 14, 1902.

³ T. C. CHAMBERLIN: *Jour. Geol.*, vols. v-viii. 1897-1901.

Chamberlin's text book of geology may be consulted, for the more exact and extended exposition of these theories. The present purpose is to indicate their application to the evolution of land vertebrates.

PERMANENCY OF THE OCEAN BASINS

In the first place, we may note that they depend as a fundamental basis on the general permanency of the great ocean basins. The conti-

FIG. 1.— *Zoölogical regions on north polar projection*

The areas within the continental shelf (100-fathom line) are left unshaded. This map represents the true relations of land and water in the northern hemisphere far more correctly than does the usual Mercator projection. The unity of Arctogaea and the direct relation is obvious between the various degrees of isolation of the southern continents and of peculiarity of their fauna.

nents have been alternately partly overflowed, separated and insular, or raised to their greatest extent and united largely into a single mass. The great ocean basins have in the main been permanent. This principle is

dependent upon the known facts in regard to isostasy. The rocks underlying the oceans are heavier than those underlying the continents, as is proved by the deficiency of gravity measurements in the continents as compared with those in oceanic areas, the deficiency being most marked in certain, mostly high-lying parts of the continents. The conclusion appears unavoidable that in a broad way the present distribution of land and shallow water on the one hand, of deep water on the other, has been substantially unchanged.⁴ Changes in past geography have been of two kinds:

1) The continents have been alternately partly overflowed and then have emerged to the limits of the continental shelf.

2) Certain lines of unstable conditions have been subject to folding and crumpling, accompanied with great changes of level.

DISTRIBUTION OF LAND AND WATER, PRESENT AND PAST

The present distribution of land and water shows the great land masses located mostly in the northern hemisphere.⁵ The land areas, extended to the borders of the continental shelf, form a single great irregular mass with three great projections, South America, Africa and Australasia, radiating out from it into the southern hemisphere. A rise of 600 feet would unite all the land into a single mass.⁶ Only New Zealand, Madagascar, the Antilles and numerous small oceanic islands would remain separate. The East Indian islands would be part of the main land. A lowering of 600 feet would isolate North America, South America, Asia, Africa and Australia as separate insular continents. Europe would form a complex of islands and peninsulas much like the East Indies of to-day.

According to the present theory, we have recently passed through an epoch of maximum continental extension and zonal climate culminating in the Glacial age, marked by great aridity in the equatorial zones, by cold and glaciation towards the poles and in high mountain regions. A much earlier extreme of aridity and glaciation is seen in the Permian,⁷ and less marked extremes at the end of the Trias and at the beginning and end of the Cretaceous. The alternate extremes of warm moist and

⁴In this connection, however, the suggestion of Bailey Willis that the present isostatic compensation may be unusually complete must be borne in mind.

⁵It should be observed that the Antarctic continent, according to the latest data available, equals or exceeds any of the other continents in bulk of emerged land; but it is surrounded by deep oceans of vast extent.

⁶Australia forms a doubtful exception. The soundings in the Indo-Australasian region are insufficient to determine with certainty whether or not there is any continuous bridge within the 100-fathom line.

⁷The earlier Paleozoic extremes of aridity—Cambrian and Devonian—do not come within the scope of this discussion.

uniform climates are seen in the early Carboniferous, in the Jurassic, mid-Cretaceous and Eocene. Now the base-leveling and overflow conditions are obviously favorable to the expansion and growth of marine life, especially of the littoral and shallow seas. The conditions of complete emergence of the continents and restriction of the littoral life to the steep and narrow border of the continental shelf will be unfavorable and will tend to what Chamberlin calls restrictive evolution of faunas.

FIG. 2.—*The southern continents, south polar projection*

Ocean depths of 100-1000, 1000-2000, and over 2000 fathoms indicated by progressive shading. Less than 100 fathoms unshaded. The steep margins of the continental shelf are indicated by hachures. The isolation of the southern continents is in contrast to the unity of the northern land areas.

Conversely on land, the great emergence of the continents will tend to expansional evolution and cosmopolitan faunas, while their partial overflow and isolation will tend to the restriction of land migration and the development of provincial faunæ.

EFFECTS OF ALTERNATIONS OF ELEVATION AND CLIMATE UPON EVOLUTION OF TERRESTRIAL FAUNAS

Associated with the isolated continents, we have moist tropical uniform conditions of climate, and to this the provincial land faunæ of

these periods will be especially adapted. The periods of continental emergence were periods of arid and markedly zonal climate, and the faunæ must adapt themselves to these conditions. Such conditions, while favoring the spread and wide distribution of races, would be unfavorable to abundance of life and the ease with which animals could obtain a living. The animals subjected to them must maintain themselves against the inclemency of nature, the scarcity of food, the variations of temperature, as well as against the competition of rivals and the attacks of enemies. In the moist tropical climatic phase, animals would find food abundant and temperature relatively constant; but the larger percentage of carbonic acid and probably smaller percentage of oxygen in the atmosphere during those phases would tend to sluggishness.

We should expect, therefore, to find in the land life adapted to the arid climatic phase a greater activity and higher development of life, special adaptations to resist violent changes in temperature and specializations fitting them to the open grassy plains and desert life. In the moist tropical phase of land life, we should expect to find adaptations to abundant food, to relatively sluggish life and to the great expanse of swamp and forest vegetation that should characterize such a phase of climate.

The oncoming cold and arid conditions should appear first at the poles and spread towards the temperate and tropical regions. Owing to the distribution of the great land masses, this would involve a general tendency for the great migrations resulting from the

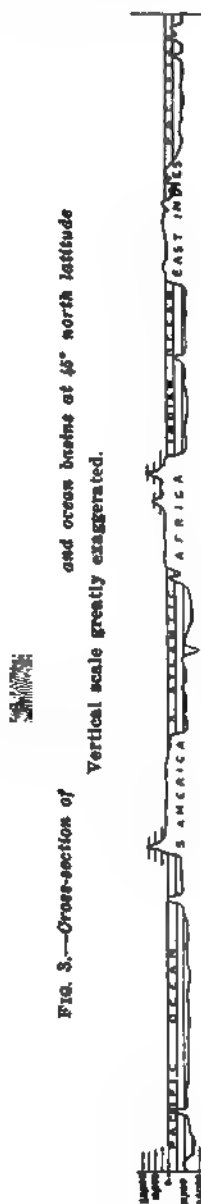


FIG. 3.—Cross-section of
and ocean basins at 45° north latitude
Vertical scale greatly exaggerated.



FIG. 4.—Cross-section of continental platforms and ocean basins at the equator
Vertical scale exaggerated about 170 times.

emergence of the continents to be outward from the two great northerly masses, and especially from Asia. The tropical and southern continents would be the refuge of the less adaptable and progressive types.

This phase of climate should, therefore, favor a higher development and greater activity of land life, while the geographic conditions favor cosmopolitan faunæ. When the climatic pendulum began to reverse its swing, the continents became isolated and their faunæ developed independently; but the dominant animals of these faunæ when first isolated would be those previously developed during the arid phase, and these would readapt themselves to the new conditions of moist and uniform climate, of prevalent forest and swamp and of abundant food.

COMPARISON WITH THE PALEONTOLOGICAL RECORD

How far do these *a priori* deductions correspond with the facts, as obtained from the geological record? In the first place, we should keep in mind that our record of the land life of the emergence phases is very defective. The sediments of this phase, where deposited along the continental margins, are limited in area, thick and very barren, the conditions of their deposition being generally unfavorable to the preservation of fossils. The sediments of the interior of the continents, river and floodplain deposits of the Cenozoic era are more widespread and furnish an extensive record of Tertiary and Quaternary land life; but those of the preceding periods of aridity have been re-eroded and carried down to the marginal and littoral areas during the period that has elapsed since they were first deposited. Of the pre-Tertiary epicontinental deposits, only the coast margin, littoral and marine deposits are extensively preserved. That means that the record of Mesozoic and Paleozoic land life as preserved to us is chiefly the record of the coast-swamp and low-land regions and that we know nothing of the life of the upland, except by a rare accidental preservation. In considering the evidences of climatic adaptation during the Mesozoic, this must be kept clearly in mind.

The great mass of evidence in favor of adaptation to progressively arid climate and of dispersal from the northern land regions is derived from the recorded history of the Mammalia during the Tertiary and Quaternary and from comparative distribution. It has long been known that the distribution of mammals is due chiefly to the land mass, and the connection of the distribution with refrigeration in the polar region.

(1778) by Buffon.⁸ With a clearer perspective of geologic time and far more exact records, it is clear that most of this deployment and dispersal of the mammalian races has taken place since the Eocene epoch of the Tertiary, although remnants of an older dispersal on the same lines are probably traceable in the present habitat of monotremes, marsupials and primitive insectivores.

INTERPRETATION OF SUPPOSED EXCEPTIONS

There has been a disposition in recent years among students of geographical distribution to lay weight upon certain apparent exceptions to this general rule, where the geological record has not yet afforded evidence to support the northerly origin of certain groups now limited to the southern continents or to the tropics and to infer various equatorial or southern continental connections during or previous to the Tertiary, in order to account for these exceptions.⁹ To these hypotheses, there are several objections:

1) The evidence for the general permanence of the great ocean basins and their maintenance formerly, as now, by isostatic balance is very strong and direct, and before allowing any exceptions, we should be very sure that no other explanation will serve.

2) The instances adduced in favor of former equatorial or southern connections are distinctly exceptional cases in the fauna, which may, in all the cases I have examined, be accounted for by appealing to the imperfection of the geologic record, by parallelism or by the rare accidents of over-sea transportation.

3) The existence of such land bridges would present the opportunity for migration of other parts or of the whole of certain fauna, which has evidently not occurred. I can see no good reason why the only animals which availed themselves of such continental bridges should be the ones which might be accounted for in other ways, while those which would furnish conclusive proof are invariably absent.

⁸ See K. v. Zittel, *History of Geology and Palaeontology*, p. 43, for a brief summary of Buffon's views on this subject. The theory has been more fully presented by many subsequent writers. In recent years, it has been very ably set forth in its relations to Tertiary mammalia by Dr. J. L. Wortman (*Amer. Jour. Sci.*, 1903). A very readable little pamphlet by G. Hilton Scribner, entitled "Where Did Life Begin", 1884, while totally deficient in geological perspective, sets forth very clearly the diverse effect upon migration of the general trend of the great mountain system, north and south in the New World, east and west in the Old. Alfred Russell Wallace is, I believe, usually regarded as the foremost exponent of this theory on the distributional side; but it is necessary to catalogue the principal exponents of a view so long and so gen-

eralized. Argentine paleontologist, Florentino Ameghino, has for twenty years advocated a theory the direct opposite to that currently held, and he would account for all groups of mammalia from a South American center of dispersal. Objections and objections to this theory will be discussed in the sequel.

4) Many students of geographic distribution proceed on what appear to me to be wholly false premises. They assume that the habitat of the most primitive living member of a race is the original habitat of the race, the most advanced forms inhabiting the limit of its migration. It seems to me that we should assume directly the reverse of this.

PRINCIPLES OF DISPERSAL

Whatever agencies may be assigned as the cause of evolution of a race, it should be at first most progressive at its point of original dispersal, and it will continue this progress at that point in response to whatever stimulus originally caused it and spread out in successive waves of migration, each wave a stage higher than the previous one. At any one time, therefore, the most advanced stages should be nearest the center of dispersal, the most conservative stages farthest from it. It is not in Australia that we should look for the ancestry of man, but in Asia.

In the same way, in considering the evidence from extinct species as to the center of dispersal of a race, it has frequently been assumed that the region where the most primitive member of a race has been found should be regarded as the source of the race, although in some instances more advanced species of the same race were living at the same time in other regions. The discovery of very primitive sirenians in Egypt while at the same time much more advanced sirenians were living in Europe has been regarded as evidence that Africa was the center of dispersal of this order. It is to my mind good evidence that it was not. It is very common to see references to the African facies of the Miocene or Pliocene mammals of Europe; but it is much more correct to say that the modern African fauna is of Tertiary aspect and is in large part the late Tertiary fauna of the northern world, driven southward by climatic change and the competition of higher types.

The chief arguments advanced in support of the method here criticized appear to be that the modification of a race is due to the changes in its environment and that the primitive species are altered more and more as they spread out or migrate into a new environment; but, assuming that a species is the product of its environment, the conclusions drawn would only hold true if the environment remained constant. This is assuredly not the case, and if it were there would be no cause left for the species to change its range. In fact, it is the environment itself, biotic as well as physical, that migrates, and the primitive species are those which have followed it, while those which remained have had to adapt themselves to a new environment and become altered thereby. Probably, it is never the case that the environment of the marginal

species is an absolute replica of the older environment of the race. In many cases, it must be profoundly modified by its invasion of new regions, and there are many features in the evolution of a race which appear to be only partly, if at all, dependent on environmental change. But to assume that the present habitat of the most generalized members of a group, or the region where it is now most abundant, is the center from which its migrations took place in former times appears to me wholly illogical and, if applied to the higher animals as it has been to fishes and invertebrates, it would lead to results absolutely at variance with the known facts of the geologic record.

REVIEW OF THE EVOLUTION OF VERTEBRATE LIFE

To my mind, this hypothesis of the evolution of land life in adaptation to recurrent periods of aridity supplies a satisfactory background of cause for the whole evolution of the higher vertebrates.

We may set aside earlier periods of aridity and continental extension signalized by the development of invertebrate land types, whose early terrestrial adaptation is wholly hypothetical, since the known portion of their history is so small and so remote from their origin that we cannot project it backwards with any sort of exactness. As Barrell has pointed out, the arid period of the late Devonian coincides with the probable time of the first adaptation of vertebrates to terrestrial life. In the arid period of the Permian, we see the conditions more clearly prevalent which favored a much more extensive development of land life, and this period marks the rise and early differentiation of the Reptilia. That reptiles first differentiated from amphibia as a dry-land adaptation seems to be obvious; that the period of their rise corresponded with the greatest extreme of aridity, continental emergence and glaciation between Cambrian and Quaternary would, I think, be also generally admitted. The dominant order of land reptiles up to the close of the Mesozoic was the dinosaurs, preëminently a dry-land adaptation in their inception, since their most marked characteristic lies in their long limbs, bipedal progression and general parallelism in proportions and structure to the large ground-birds of modern times, which are to-day peculiarly inhabitants of arid regions. The relationship and origin of the more specialized, mostly gigantic, dinosaurs of the later Mesozoic can be best explained by regarding them as a succession of derivatives from smaller and more lightly constructed upland dinosaurs, mostly unknown to us, the larger and more specialized types being re-adapted to a swamp life and inhabiting the coast marshes whose sediments are still preserved, while the more direct

line of dinosaurian evolution inhabited the uplands, where the sediments, if such were deposited, have long since been removed by erosion, and the fauna is consequently unknown to us, except by inference. It is quite impossible to trace the evolution of the dinosaurian phyla through the same nearly direct series of known forms as can be done in the phyla of Tertiary mammals. But I may observe that if our knowledge of the Tertiary sediments were limited to the coastal swamp deposits,—if in this country, for instance, we knew only the Tertiary of the Atlantic and Gulf coasts,—we would be equally at a loss for any direct ancestral series illustrating the evolution of the Mammalia.

The same explanation, namely, that the geological record in the Mesozoic is defective where its evidence would be most direct as to the evolution of land vertebrates, applies both to birds and to mammals, but especially to the former. The exceeding scantiness of fossil birds and mammals during the Mesozoic and their apparently sudden appearance in the record, already well deployed, is often explained by supposing them to have evolved mainly in some continent not yet investigated. It appears to me that a simpler and more probable explanation lies in the fact that the formations of the interior of the Mesozoic continents have in general not been preserved and that this facies of the Mesozoic faunæ is consequently unknown to us.

It may be objected that remains of dry-land animals would be brought down by rivers and deposited in their deltas and thus preserved to our day. This may, of course, occur in exceptional cases. How rare is the exception, we may judge from the exceeding rarity of remains of land animals in true marine deposits, where the chances for their preservation should be almost equally great.

In marked contrast with the evolutionary record among dinosaurs, stands the record of development of the non-marine crocodiles and chelonians, whose normal habitat was the swamp regions and whose more direct evolution is in consequence recorded since the Mesozoic. Remaining in a constant environment, they evolved but little, though their abundance and geographical distribution varied.

Throughout all the evolutionary history of the vertebrates, we see numerous examples of races which, having become adapted to a higher plane of life, have re-invaded a lower plane. In each instance, the higher organization and greater activity acquired in the higher plane have caused them to become dominant, increase rapidly in size and spread widely in the absence of efficient competition. Thus we find various groups of marine reptiles appearing with apparent suddenness in the Mesozoic, becoming very abundant and of gigantic size, spreading very widely and then

being replaced by new invasions from the land instead of evolving further in their new habitat. The ichthyosaurs, plesiosaurs, mosasaurs, sea-crocodiles, sea-turtles, are examples of this sort among reptiles; the cetaceans and seals among mammals. These invasions from a higher to a lower plane of active life have been very frequent, so that their recognition is necessary in tracing evolutionary series. The converse movement from a lower to a higher plane, as from aquatic to amphibious, from amphibious to terrestrial, from terrestrial to arboreal or aërial, have been slow, difficult and for the most part have occurred but once or twice in the geological history of vertebrate life. The higher field once occupied, the lower adaptation was handicapped in its attempts to rise.

IMPERFECTION OF THE GEOLOGICAL RECORD

Everyone is familiar with Darwin's classic illustration of the imperfection of the geological record;¹⁰ but I doubt whether the majority of paleontologists realize how very imperfect our record is, even to-day. We know more about fossil mammals in proportion to their modern numbers than about any other of the larger groups of land animals; yet the number of species of which we have any adequate knowledge is but a minute fraction of the number which must have lived since the class first came into existence. Were it not so, the fossil species would vastly outnumber the living forms; as it is, they form a small minority. Moreover, the greater number of recorded fossil species are hardly more than *nomina nuda*, each known from a single fragmentary jaw, a tooth, a scale, a broken bone, indicating indeed that an animal otherwise unknown lived at a certain time in a certain locality but giving very little information as to its entire structure, its habits, its geographical and geological range. The relationships of these imperfectly known species, provisionally stated by the describers and adopted without the query by subsequent writers, are one of the most fertile sources of error in paleontological theories.

Mammals undoubtedly existed during the entire Mesozoic, an era about three times as long as the Cenozoic. Two thirds of their evolution must have taken place during that time; and by the end of it, the principal modern orders were already defined. But we have not a skeleton, or even a skull of a single Mesozoic mammal.¹¹ Two jaws and a few teeth from the Triassic, a number of more or less fragmentary jaws from the upper Jurassic and various teeth and fragments of jaws from the uppermost Cretaceous represent the sum total of our real knowledge of the first two

¹⁰ In the *Origin of Species*, at the end of Chapter X.

¹¹ Setting aside *Tritylodon* as of doubtful affinities.

thirds of the evolutionary history of the Mammalia. The rest is theory and hypothesis.

Assuredly, we have no right to assume that the few species which have been founded upon these fossil remains represent at all adequately the number and variety of mammals that lived during the Mesozoic; nor can we even suppose that they fairly represent them. Only two¹² of the numerous phyla of early Tertiary mammals can be at all directly derived from known Mesozoic ancestors. The rest are descended from unknown forms. We may suppose, from the evidence at hand, that the known Jurassic and Cretaceous mammals were arboreal swamp-dwellers and that the chief reason why we know so little of the Mesozoic mammals is that the deposits of the upland regions where they chiefly lived have not been conserved to our day, or at all events have not been recognized and sufficiently explored for fossils.

In the Tertiary, mammals suddenly spring into (apparent) prominence, mainly, it may be assumed, because the fluviatile and eolian formations of the Cenozoic still exist in many localities, although they are being rapidly eroded and carried down to the coastal swamp and sea margin areas of deposition. Epicontinental deposits of Eocene age are rare and scattered, and our knowledge of Eocene mammals is obtained from only a few localities and largely from fragmentary specimens. Through the following Tertiary epochs, these deposits become progressively more extensive and abundant, and our knowledge of fossil mammals is correspondingly greater. Finally, in the Quaternary, they form a mantle over most of the earth's surface, and the fossil mammals are so well known and so many specimens from so many localities have been found that we can get a fairly accurate idea as to the range of many species, not merely as discovered in one or another continent, but as to what parts of that continent they inhabited.

If our knowledge of fossil mammals is incomplete, that of fossil birds is very much more fragmentary. They probably came into existence at about the same time as mammals, but the early stages of their evolution are even more obscure, and comparison of the living members of the class affords less evidence than with mammals as to their source and course of progress. They are even rarer than mammals in the Mesozoic. Two skeletons and a feather from the Jurassic of Bavaria, a number of skeletons and fragments from the late Cretaceous of Kansas and a few fragments of the skeleton from Cretaceous formations in New Jersey and Europe,—these are all we know of a class which was probably very large

¹² *Plagiaulacidae* and *Didelphyidae*.

and varied during the Mesozoic. Our knowledge of Tertiary and Quaternary birds is much more extensive, but it bears no comparison to our acquaintance with Tertiary mammals, and the materials on which it is based are for the most part very fragmentary, their identification often questionable. We may say, however, that Mesozoic birds are more completely known than Mesozoic mammals; that is to say, we know the entire skeleton of two or three, and in consequence can estimate their affinities more certainly and exactly. On the contrary, the fragmentary remains of Cenozoic birds make our estimates of their affinities proportionately uncertain and inexact.

The Reptilia are a more ancient class than either birds or mammals and include the ancestral types of both. Our knowledge of fossil reptiles, in comparison with their probable numbers and variety, past and present, is much less than with mammals, more than with birds. We cannot, as with Tertiary mammals, reconstruct approximate evolutionary phyla of the several races from known fossil forms; yet the evidence is sufficient to give a reasonable basis for inferential phyla of some degree of exactitude among many of the Mesozoic and Tertiary reptiles. But the origin of the Reptilia, like that of the Mammalia, is wrapped in obscurity, and the interrelationship of the more ancient groups is a puzzle not yet solved. We have a fairly extensive acquaintance with the Reptilia of certain habitats at certain epochs; but there were evidently long intervening periods and important faunal facies of which we know nothing or next to nothing.

The Amphibia are not a very important group at present and are almost unknown as fossils, except for the so-called armored amphibians or Stegocephalia, whose relations to the modern frogs, toads and salamanders are still far from clear. This ancient group was abundant and varied in Carboniferous, Permian and Triassic times and is supposed to have given rise to the Reptilia; but the relationship has not been satisfactorily demonstrated by fossils, nor is there direct evidence of the interrelationship of the several groups of stegocephalians.

A wide gap separates the oldest four-footed vertebrates from any known fishes, living or extinct.

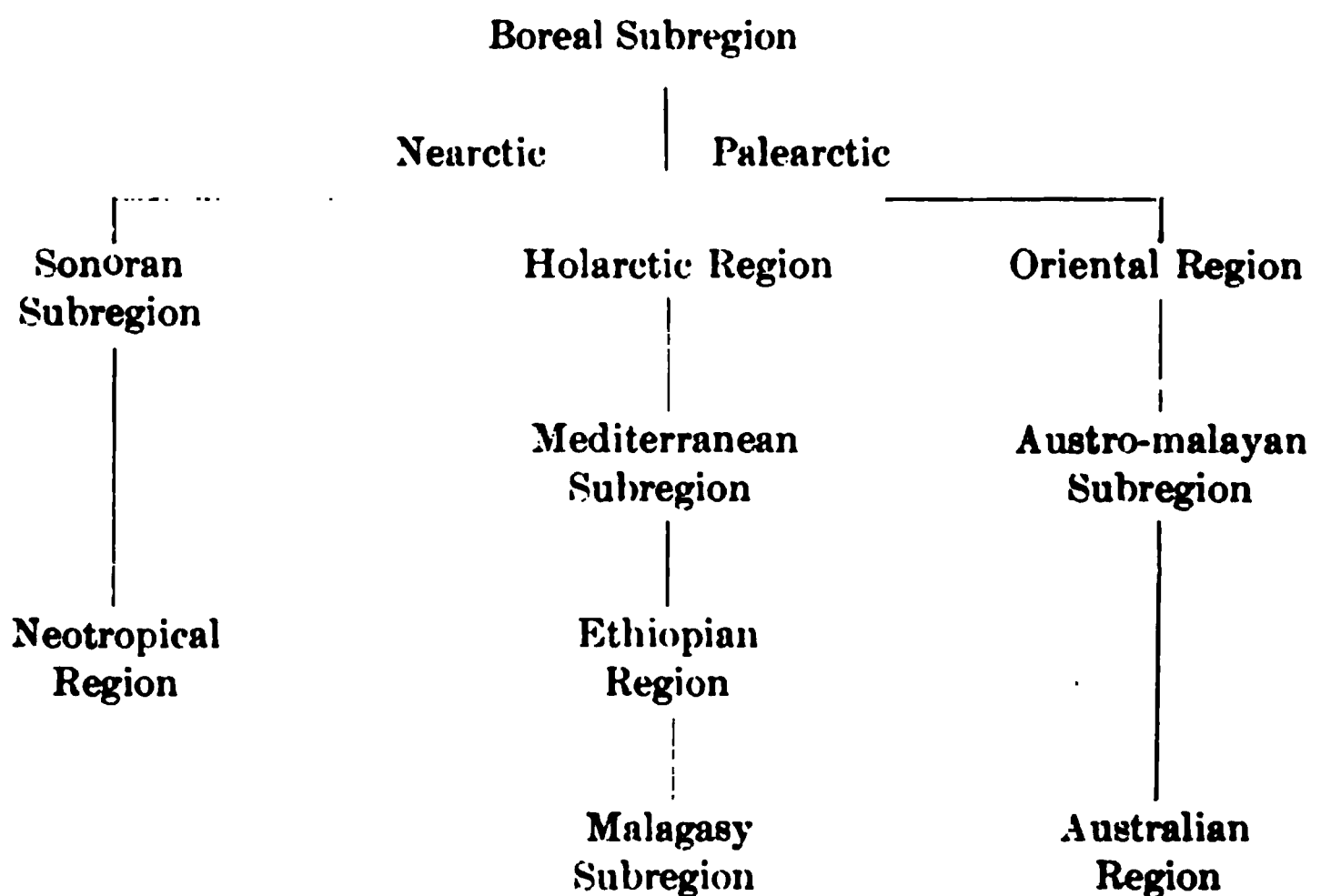
ZOÖLOGICAL REGIONS, PAST AND PRESENT

The zoölogical divisions of the land surface of the earth are given by Lydekker¹³ as follows:

¹³ RICHARD LYDEKKER: A Geographical History of Mammals. 1896. This is a modification of the regions proposed by Selater in 1858 (Jour. Proc. Linn. Soc., vol. II, pp. 130-146) and adopted by Wallace in 1876 (Geographical Distribution of Animals).

1. Australian	region	}	Notogæic Realm
Polynesian	"		
Hawaiian	"		
2. Austro-malayan	"	}	Neogæic "
3. Neotropical	"		
4. Malagasy	"		
5. Ethiopian	"	}	Arctogæic "
6. Oriental	"		
7. Holarctic	"		
8. Sonoran	"	}	

The Polynesian and Hawaiian regions have played no material part in the evolution of mammalian faunas and do not call for any special consideration here. The limits of the remaining regions are shown on the accompanying map. The eight principal "regions" are by no means equally distinct, and their combination into three "realms" does not remove this defect. Of the five included in Arctogæa, the Sonoran is closest, the Malagasy and Ethiopian farthest removed from the central Holarctic region, if we take into account both the recent and extinct faunæ. The true relations of the several regions might perhaps be better represented thus:



The Holarctic region in its broader sense, including the Sonoran and Mediterranean subregions, is bounded by the tropic of Cancer, except where (as in Asia) the dispersal of the fauna from a northern center has been hindered by east and west mountain systems, or (as in America) facilitated by north and south mountain systems. The Sonoran sub-

region includes most of the United States and northern Mexico; the corresponding subregion in the western half of the Old World is the Mediterranean, including Europe south of the Alps and Pyrenees, part of southwestern Asia and Africa north of the Sahara desert.

The Oriental region corresponds in the eastern part of the Old World to the Mediterranean and Sonoran subregions, but, partly because it includes the great East Indian islands and partly because of the barrier interposed by the Himalayan ranges, it is more clearly differentiated from the Holarctic and may best be regarded as a region of itself.

	NEOTROPICAL	HOLARCTIC	ORIENTAL	ETHIOPIAN	AUSTRALIAN
MODERN	<i>Holarctic fauna dominant. A few survivors of the autochthonous fauna</i>	<i>Man cosmopolitan. Higher Ruminants. Myomorph Rodents. Dogs, Cats, Bears</i>	<i>Antelopes, Elephants, Cattle, Deer, Rhinoceros (Fauna of Pliocene and Pleistocene Holarctic)</i>	<i>Antelopes, Horses, Elephants, Rhinoceros</i>	<i>Herbivorous and Carnivorous Marsupials. A few Placentals</i>
PLEISTOCENE	<i>Giant Edentates. Macrauchenia and Toxodon. Holarctic Carnivores & Ungulates</i>	<i>Man. Modern genera of Placental Mammals. Mastodons, Elephants, Horses, Rhinoceroses.</i>	<i>Elephants, Cattle, Rhinoceroses, Horses, Camels.</i>	<i>Modern? genera of African mammals</i>	<i>Herbivorous and Carnivorous Marsupials.</i>
PLIOCENE	<i>Autochthonous fauna dominant. Earliest invasion of Holarctic fauna</i>	<i>Mostly modern genera of Placental Mammals. Elephants & Mastodons. Rhinoceroses. Monkeys</i>	<i>Mastodons, Elephants, Rhinoceroses, Giraffoid Ruminants. 3-Toed Horses etc.</i>		
MIOCENE	<i>Peculiar types of Ungulates. Edentates. Marsupial Carnivores</i>	<i>Modern families of Placental Mammals. Mastodons. Monkeys</i>	<i>Primitive Ruminants. Mastodons etc.</i>	<i>Mastodons? Rhinoceroses</i>	
OLIGOCENE	<i>Evolution of peculiar types of Ungulates etc.</i>	<i>Evolution of modern families of placental mammals</i>		<i>Peculiar types of Ungulates. Invasion of Holarctic fauna</i>	
EOCENE	<i>Primitive Placental Ungulates. Marsupial Carnivores</i>	<i>Modern orders of Placental Mammals (Ungulates, Carnivores, Primates)</i>			
PALEOCENE		<i>Primitive Placental Carnivores and Ungulates</i>			
CRETACIC		<i>Marsupials dominant. No Placentals positively known</i>			

FIG. 5.—Characteristic features of the mammal faunæ in different zoölogical regions at successive epochs of the Cenozoic

Austromalaya is the debatable ground between the Oriental and the very distinct Australian region; but the consensus of opinion classes it by preference with the Australian. It includes Celebes, the Moluccas, Timor and smaller islands and is separated from the Oriental region by "Wallace's Line."

The Australian region includes Australia, New Guinea and Tasmania and is the most remote and archaic of all the great (continental) regions of the globe. New Zealand is included in the Polynesian (island) region.

The Ethiopian region is connected with the Holarctic by the Mediterranean subregion. It is perhaps more distinct than the Oriental, cer-

tainly less so than the Neotropical region. The Malagasy subregion is related not to the modern but to the Tertiary Ethiopian region; its supposed Oriental affinities will be considered later.

The Neotropical region is connected with the typical Holarctic through the Sonoran, as the Ethiopian is through the Mediterranean intermediates; but the relationship is more remote. During the Tertiary, the region was much more distinct than it is now.

In considering the records of past faunæ of one or another of these regions as a guide to the dispersal of different groups, it is very necessary to remember that our records are often chiefly or wholly from a small part of the region, often far from typical.

Our knowledge of Palæarctic faunæ in the early Tertiary is wholly from western Europe, an outlying, marginal part, more or less submerged and archipelagic. Its relations to the main body of Palæarctic land life were probably much like those of the East Indian archipelago to the continental portion of the Oriental region. In the later Tertiary and Quaternary, we obtain a broader outlook on the Palæarctic fauna, but even then it is incomplete.

In the Oriental region, we know nothing of the land life of the early Tertiary, and in the later Tertiary we know only the life of its northern borders, close to the Palæarctic region and doubtless more nearly approximating the Palæarctic fauna then than now, as the Himalayan barrier was less complete.

The result of these two facts will apparently be that the early Tertiary Palæarctic fauna will appear by the record to be less progressive than it really was and that the Tertiary Oriental fauna will appear to be more progressive than it really was. In the Nearctic Tertiary, the record is chiefly confined to the Western plains; we know little of the Canadian Nearctic—presumably more progressive. In the forested regions of the East and South, where we might expect to find primitive survivals, or on the Pacific coast, where we might expect to see stronger Palæarctic influence, our knowledge is very imperfect, although the few available data are in conformity with *a priori* deductions.

In the Neotropical region, our chief dependence is upon the Argentine faunæ which should be both the most progressive and least influenced by Northern immigration.

In the Ethiopian region, we have but a single glimpse of the Tertiary land fauna, and that is derived from Egypt, where we might expect to find a transitional fauna, combining true Ethiopian autochthones with immigrants from Palæarctic or northwestern Oriental faunæ. But, since the water barriers to the north of Egypt were more extensive and the

desert barrier to the south less developed in the early Tertiary than they are to-day, we should expect that the autochthonic element would be dominant and that Tertiary Egypt belonged to the Ethiopian zoölogical region, although modern Egypt does not.

These may serve as instances of the caution with which the geological record must be used in attempting to estimate the position and source of regional faunæ.

The regions here adopted are based primarily upon the present and past distribution of mammals. Birds, reptiles, amphibians, fresh-water fishes and the various groups of terrestrial invertebrates are not wholly in accord with this arrangement so far as their present distribution is concerned. This is partly because the means and limitations of their dispersal differ, chiefly, as I shall attempt to show, because so little is known of their former distribution.

FORMER BARRIERS AND BRIDGES

The general principle of dispersal on the lines of the present continents is open to an obvious objection. The outlines and connections of the continents were different in former times. The relations of land and water were not the same. In fact, if one depends upon a text-book knowledge of geology he may find authority for an assured belief that they were fundamentally and altogether different in different geologic periods. It is necessary therefore to point out that the stratigraphic no less than the life record is a defective one, and that the really proven changes in the distribution of land and water are limited to those summarized on page 175. The geotectonic hypotheses so ably and brilliantly elaborated by Suess,¹⁴ Haug¹⁵ and other writers, are not facts but theories, and I must confess to a decidedly skeptical attitude towards some of their conclusions. There are too many gaps in the chain of their arguments; too many known facts with which their conclusions appear to be inconsistent.

The permanency of the continental platforms is indicated by the absence of abyssal deposits in their sedimentary succession wherever this has been adequately studied. The platforms have been extensively overflowed by shallow seas, but such submergences were temporary, and intervening periods of uplift are indicated by gaps in the marine succession. Where the geologic records are fragmentary, widely scattered and imperfectly correlated, there often is a tendency to exaggerate the extent and permanency of such overflows, as also to assume extensive unknown continents to account for the existence of clastic sediments which were more

¹⁴ E. SUESS: *Antlitz der Erde*. 1888-1901.

¹⁵ E. HAUG: *Traité de Géologie*. 1912.

probably derived from unsubmerged adjoining portions of the existing continents. We are apt to assume that great displacements of strata involve correspondingly great changes of level. They do not necessarily; more probably, in most instances, the erosion has kept pace more or less closely with the displacement. Even where great changes of level have occurred, they often have been, and more often may have been, of restricted extent and compensated by opposite changes in regions immediately adjoining, and most of them have had but little extensive or permanent effect on the general configurations and relations of the continental platforms.

The relative permanency of the North American continent is very clearly brought forward in Schuchert's maps.¹⁶ Yet even here, if one may venture a criticism on so thorough and conservative a study, there is a certain loss of conservatism where the outlines run into territory where the evidence is inadequate, as in the Antilles and the Arctic seas. The imperfect data available for the South American continent appear to indicate general conditions very similar to those of its northern neighbor; nor does it appear that Africa and Australia were any less permanent land platforms. Northern Eurasia appears to have been similarly permanent, but across Central Europe and extending southeastwardly to the East Indies lies a broad strip of disturbance where great changes have occurred during later geologic time. But the extent and permanency of the great central sea which is so frequently depicted as interposing a broad ocean between the Holarctic and the Ethiopian and Oriental land masses is by no means certain, especially as regards its eastward extension. I cannot find in the recorded facts proof that it afforded any more continuously effective bar to dispersal along the lines of the present continental relations than did the middle Cretaceous overflow in North America or the early Tertiary one in South America.

Perhaps the most widely accepted departure from the permanency of the ocean basins is the supposed Gondwana Land, invented to account for certain similarities in southern Paleozoic floras, and since used to account for almost all cases of similarity among southern floræ and faunæ which were not demonstrably due to dispersal from the northern continent. This theory has in its original form gone so long uncontested that it is very generally regarded as incontestable. New discoveries have been interpreted in terms of it, the weakness of the original evidence, the possibility that it might be otherwise interpreted, has been forgotten, and like the Nebular Hypothesis, it has become almost impossible to dislodge it from its place in the affections of the average geologist.

¹⁶ CHARLES SCHUCHERT: Bull. Geol. Soc. Amer., vol. 20, pp. 427-606, pll. xlv1-cl. 1910.

If the distribution of animals be interpreted along the lines here advocated, there is no occasion for a Gondwana Land even in the Paleozoic. But it is chiefly as affecting Mesozoic or Cenozoic dispersal that we are here concerned with it. One may summarize the arguments for it by saying that a considerable number of groups of animals and plants which are absent in the northern world, either living or fossil, are found in the southern continents and some of them in certain oceanic islands as well. Most of the groups are unknown or almost unknown as fossils; those which have any considerable fossil record are steadily being eliminated from the list by the progress of discovery, showing that they or their ancestors did formerly inhabit the northern world. The remaining groups agree with those southern faunal groups which have admittedly come from the north, in being of primitive and archaic type and in that their representatives in the different southern regions are but distantly related, the remoteness being in a very direct proportion to the present isolation of the region.

There are a few instances of exclusively southern types closely related (e. g., *Galaxias*); but, although they have been cited in corroboration of the evidence from the groups above mentioned, they are in fact, if thus interpreted, directly contradictory. For the distant relations of the one series is interpreted to mean a very ancient connection, but isolation since; while the other series would indicate a very recent connection and earlier isolation. The explanation here lies not in a northern ancestry, but that the ocean does not form an impassable barrier to their dispersal. This has been proven in the case of *Galaxias*; it is probably the explanation of all similar distributions.

The relations of the *Glossopteris* flora are a different and far more complex problem of distribution. The clue to its interpretation lies perhaps in its association with Permian glaciation; but it is outside the limits of the present essay and will not be discussed here.

REGIONAL CORRELATION

The geological correlation of widely distant formations is so intimately bound up with problems of geographical dispersal and migration that the two series of problems must needs be studied and solved together. We cannot arrive at a correct understanding of the history and causes of the geographical distribution of animals, present and past, without correct correlation of the geological succession in different regions. Nor have we, up to the present time, any reliable methods of exact correlation in widely distant regions except the comparison of fauna and a considera-

tion of their source and the history of their migration and dispersal. Absolute standards, as of world-wide changes in physical or climatic conditions, may serve in the future to give us broad lines of correlation independent of paleontology; but at present their universality is hypothetical, the exact train of physical phenomena which they entail and the indices by which they may be recognized in the stratigraphic succession are imperfectly known. Paleontology is for the present our sole recourse in correlation. Probably it will always be our chief dependence, at least in exact and detailed comparison.

SYNCHRONISM AND HOMOTAXIS

The ordinary methods of paleontologic correlation can be applied with accuracy and certainty only over limited areas of the earth's surface. When applied to far-distant regions, we meet first with the difficulty that there is little identity of faunæ, only an equivalence more or less exact. Nor can we be sure that equivalent or even identical forms were contemporaneous in all parts of the earth. They certainly are not so to-day. The modern land fauna of Australia, as Huxley long ago insisted,¹⁷ is in its broad lines a Mesozoic fauna. Examined in detail, it shows indeed the marks of a long period of independent evolution and specialization. Yet the degree and amount of specialization is far less than that which the faunæ of the northern continents have undergone during the Cenozoic. The modern fauna of the East Indies or of Central Africa has a great deal in common with the later Tertiary faunæ of Europe and northern Asia. Central America and tropical South America bear similar relations to North America. While Huxley's dictum that an older fauna in one region may be homotaxial with a later fauna in another does not apply to the extent of involving identity of all or most of the species, yet it very clearly does apply in a broad way to the land faunæ and probably to a less extent to the marine faunæ as well. The rate at which evolution and differentiation progress varies as between the faunæ of different regions. It varies as between the different constituents of a fauna. Neither the partial identity nor the general equivalence of two faunæ is sufficient to prove them synchronous, except under certain conditions to be considered later.

Another method very generally used in correlation of faunæ which contain little or nothing in common consists in an estimate of their relative antiquity as indicated by the proportion of extinct to surviving species or genera. This also involves the assumption that the rate of progress

¹⁷ T. H. HUXLEY: Q. I. G. S., vol. xviii, pp. xl-llv. 1862.

of evolutionary change is constant in all parts of the earth, at least for members of the same group. But if the rate varies in different regions for the fauna as a whole, we have no reason to believe that it would be constant for common or similar groups.

The practical application of this method is very unsatisfactory. In illustration of this, I may instance the widely divergent views entertained by different authorities as to the age of the later geological formations of Argentina in comparison with European standards. Able and authoritative discussions of this problem have appeared within the last few years by Ameghino,¹⁸ Roth,¹⁹ Gaudry,²⁰ Scott,²¹ Hatcher,²² Ortmann,²³ Stanton, von Ihering, Wilckens, Cossmann, Wiman and others, dealing with the vertebrate and invertebrate fossils and stratigraphic relations of the formations. The field work has been extensive, the collections large, the faunæ are large and varied and in large part well known; but the results are widely discordant. The amount of discordance is indicated by the correlation of the four principal terrestrial formations, as given by Ameghino, Roth, Gaudry and Schlosser.

The correlation of widely distant formations is so intimately bound up with problems of geographic distribution and migration that the two series of problems must be studied and solved together. The methods relied upon by Roth and Ameghino are substantially the same as those generally used by northern authors. Why then do they lead to such discordant results? It is because the data on which they rest prove not contemporaneity but homotaxis. Granting that two faunæ in widely remote regions contain the same proportion of extinct species, granting that they represent equivalent stages of evolutionary progress, they are not thereby shown to be contemporaneous, unless they are at the same distance (measured not in miles but in difficulty of advance) from the main center of dispersal of the fauna which they contain. Very obviously, if

¹⁸ FL. AMEGHINO: "L'Age des Formations Sédimentaires de Patagonie," *Anal. Soc. Cient. Argent.*, tom. L, LIV: pp. 1-231 of separata. 1903. "Formations Sédimentaires du Crétacé Supérieur et du Tertiaire de Patagonie," *Anal. Mus. Nac. Buenos Aires*, tom. xv, pp. 1-568. 1907.

¹⁹ SANTIAGO ROTH: "Beitrag zur Gliederung der Sedimentablagerungen in Patagonien und der Pampasregion." *Neues Jahrb., Beil.-Bd.* xxvi, s. 92-150, taf. xi-xvii. 1908.

²⁰ A. GAUDRY: "Fossiles de Patagonie, etc." *Ann. de Paléont.* I. 1906.

²¹ W. B. SCOTT: *Mammalia of the Santa Cruz Beds in Rep. Princ. Univ. Exp. Patagonia*, vol. v. 1903. *Int. Cong. Zool., Berne, C.-R.*, pp. 241-247. 1905. *A History of the Land Mammals of the Western Hemisphere*. 1913.

²² J. B. HATCHER: "On the Geology of Southern Patagonia." *Amer. Jour. Sci.*, vol. iv, pp. 327-354. 1897. "Sedimentary Rocks of Southern Patagonia." *ibid.*, vol. ix, pp. 89-108. *ibid.*, vol. xv, pp. 483-486. 1903.

²³ A. ORTMANN: *Tertiary Invertebrates in Report Princ. Univ. Exp. Patagonia*, vol. iv, pp. 45-332, pl. xi-xxxix. 1902.

See for further references the bibliography in Ameghino, 1907, *supra*, pp. 3-18.

TABLE I.—*Correlation of the Four Principal Terrestrial Formations*

	Ameghino, 1906	Roth, 1908	Gaudry, 1906	Schlosser, 1912
Pleistocene	} Pampean	} Pampean	Pampean	Pampean
Pliocene				
Miocene			Santa Cruz	Santa Cruz Pyrotherium
Oligocene		Santa Cruz		
Eocene	Santa Cruz	Pyrotherium	Pyrotherium	Notostylops
Paleocene			Notostylops	
Upper Cretaceous	Pyrotherium	Notostylops		
Lower Cretaceous	Notostylops			

the principal center of dispersal of Mammalia was in the Holarctic region, the fossil mammals in southern regions invaded by that northern fauna will appear in their homotaxial relations to be more ancient than they really are. The modern fauna of South America, of Africa, of the Oriental regions, will be in the same stage of evolution as the late Tertiary and Quaternary faunæ of Holarctica. Its species will be more nearly related or equivalent to Pliocene and Pleistocene species of Europe and North America than to their modern fauna. The late Tertiary mammals of the southern continents will approximate in homotaxis the middle or early Tertiary mammals of Holarctica; and the middle Tertiary southern faunæ will approximate the early Tertiary or late Cretaceous faunæ of the north.

On the other hand, if we believe, as does Dr. Ameghino, that the principal theater of evolution of the mammals lay in the temperate regions of South America, and that the mammal population of the North was derived by migration from that center (by way of Africa across a tropical land bridge not now existing), it will be equally obvious that the southern formations will be more ancient than their homotaxis, impartially considered, would lead us to believe. The result will be to assign to the

Cretaceous period those southern faunæ which are homotaxial with the early Eocene of the North; to the Eocene those faunæ which are homotaxial with the Middle Tertiary of the North, and so on.

To a certain extent, the intercalation of marine formations may provide a check on this relationship, but it must be remembered that the same theories of dispersal may also apply to marine faunæ, wholly or in part. Homotaxial marine faunæ may be far from contemporaneous. The chief center of dispersal of marine faunæ may be assumed to be either the equatorial oceans and coasts, the northern, or the southern seas, or both north and south equally. Only when the movements of dispersal are in opposite directions on land and in the seas will the marine faunæ furnish an adequate check on the homotaxis of land faunæ; and in that case the true synchronism must be arrived at by balancing conflicting evidence derived from terrestrial and marine faunal comparisons.

It is true that if we eliminate the idea of faunal dispersal altogether and regard each race of animals as evolving and dispersing independently, governed by its own conditions and causes of change, we may in the present imperfect state of our knowledge lay out various and independent centers of dispersal for different races, whose successive appearance in one or another continent will furnish data for a true correlation. There has been a strong tendency in the last half century to work on this theory, but in the present writer's opinion at least, the supposed evidence in favor of this view is due chiefly to the imperfection of the geologic record, and its very wide acceptance to a lack of appreciation of the underlying causes of evolutionary progress and dispersal.

I do not understand how anyone can reconcile the theory that each race of animals evolves and disperses independently and that the common biotic and physical environment is not a controlling factor, with the plain fact that regional faunæ do exist to-day. The conditions that control the dispersal of one race are largely identical or correlated with those that control the dispersal of others, and every change in these conditions will affect not one race only, but a large part or the whole of a fauna, in a manner and to a degree largely identical, causing similar changes in the range of the fauna.

TERTIARY CORRELATION IN SOUTH AMERICA

Before setting forth the evidence as to the dispersal of the mammals, it is necessary to attack a problem which has caused much acrid controversy, namely, the age of the later formations of the Argentine Republic. The difference of opinion among authorities has already been indicated,

as also the fact that the true correlation is so intimately related to the direction of migration that the two problems must be settled together. In view of the great and well merited reputation of Dr. Ameghino and the immense array of data which he has marshalled in support of his theories of correlation and phylogeny, it is not surprising that they should find a very considerable acceptance, not in South America alone but elsewhere. Few scientists indeed are disposed to accept his derivation of the horse family from early South American ancestors or of the various families of Carnivora from the same source, for in these and other cases the evidence for northern ancestry is almost universally accepted as convincing; but many writers are willing to accept Ameghino's determination of the age of the Argentine formations, although more critical as to his phylogenetic views.

The two, however, must stand or fall together; and it is precisely because the Equidæ, Procyonidæ, etc., if their generally accepted phylogenies be admitted, afford incontrovertible evidence against the validity of Ameghino's correlations of the formations of the Argentine, that he has been compelled to devise different phylogenies for these cases. Few scientists will be willing to believe Ameghino's assertion that *Merychippus* and its successors in the equine phylum have nothing to do with the Anchitheriinae which they so closely resemble in teeth, in skull, in feet, in all details of the skeleton, but must be derived from the South American Notohippidæ on the strength of a much more distant resemblance in the second upper molar, unsupported by any near resemblance whatsoever in the remaining teeth or in any points of construction of skull or of skeleton. It is not my intention to present here any detailed refutation of Dr. Ameghino's argument, but to point out that if the northern origin of the Equidæ be accepted, the age of the Pampean and related formations must be far later than that he has assigned to them. The first appearance of true equines in South America is in the Pampean. The three best-known genera are *Equus*, *Hippidion* and *Onohippidion*. The first might be regarded as of Palearctic origin; the second and third have no Old World predecessors, but may be directly derived from the North American *Pliohippus*. They are, however, much larger and more progressive than *Pliohippus*, and in size, reduction of the lateral digits, etc., are equivalent to *Equus*. We can hardly doubt that they came to South America from North America, nor can I see any practical alternative to believing that *Equus* arrived by the same route. Now, the first appearance of *Equus* in North America is at the base of the Pleistocene. In Argentina, it first appears in the middle Pampean. The middle Pampean cannot therefore be older and is presumably younger than Lower

Pleistocene. *Hippidion* and *Onohippidion* are found (fide Roth) in somewhat older levels; but as they are much advanced over anything in our Middle Pliocene (Blanco), it would seem that their first occurrence in the Pampean must be placed at the top of the Pliocene or preferably in the lower Pleistocene. I conclude that the Pampean formation approximately represents the Pleistocene epoch.

Beneath the Pampean of Ameghino, but included in it by Roth, are fossiliferous beds in which certain Procyonidæ and Ursidæ are found. If we admit the North American source of these carnivora, they would indicate Pliocene age for the beds containing them. Dr. Ameghino, who regards them as Oligocene and Miocene, is compelled, therefore, to set aside the North American ancestors of the Procyonidæ and to regard them as of South American origin and the Ursidæ as either autochthonous or arriving in South America from the Old World via Africa. As with the Equidæ, the only shadow of plausibility for such phylogenies lies in the incompleteness and careful limitation of the evidence that is adduced in their behalf. *Phlaocyon* of the North American Miocene, which is intermediate between *Cynodictis* and the Procyonidæ in almost every detail of the perfectly preserved dentition, skull and skeleton is merely²⁴ "un vrai Canide sans relations avec les Procyonidés," while the South American genera are derived through hypothetical ancestors from the carnivorous marsupials of the Santa Cruz. Here again, Dr. Ameghino is compelled, in defense of his theories of correlation, to adopt these impossible phylogenies, because if the Procyonidæ are of North American origin the Argentine formations are demonstrably of later date than those which he assigns to them. *Phlaocyon* is a far more primitive procyonid than any of the South American genera. *Leptarctus* of the Upper Miocene may be their equivalent, but it is very imperfectly known.²⁵ If these Argentine genera are derived from the Oligocene *Cynodictis* and related genera of Holarctica, *Phlaocyon* being about half way between the two groups, then their age is indicated as Pliocene, not as Oligocene or Miocene. Also with the Ursidæ; to admit them as arriv-

²⁴ FL. AMEGHINO: Ann. Mus. Nac. Buenos Aires, tom. xv, p. 396. 1906. Dr. von Ihering has since attempted to prove what Ameghino merely asserted. His argument rests upon an untenable interpretation of a single feature in the dentition, ignoring all other characters of teeth, skull and skeleton, and, if true, would involve not only that *Bassariscus* has nothing to do with the Procyonidæ (which he asserts), but also that the Procyonidæ have nothing to do with the carnivora but are of wholly diverse ancestry.

See H. v. IHERING, Systematik, Verbreitung und Geschichte der sudamerikanischen Raubthiere. Archiv f. Naturg., 76 Jahrg. I. Bd., s. 113-179. 1910.

²⁵ The type of *Leptarctus* is an upper premolar of doubtful affinities. Wortman referred to it in 1894 a lower jaw from the Upper Miocene, which is unquestionably procyonid and hardly distinguishable from *Procyon*. Ameghino and von Ihering ignore this record.

ing via North America would compel Ameghino to conclude that their first occurrence in South America in these same sub-Pampean beds must be materially later than the evolution of the phylum in the Palæarctic region (Miocene) and that the genus *Arctotherium* of the true Pampean in South America, unknown in North America until the Pleistocene, indicates, like *Equus*, that the Pampean is a Pleistocene formation.

The distribution of *Smilodon* in North and South America is in exact accord with that of *Arctotherium*. The relations of the South American Proboscidea to those of North America correspond to those of the Equidæ. The Camelidæ, Cervidæ, Canidæ, etc., also support the Pleistocene age of the true Pampean. The Edentata, whose migration appears to have been in the reverse direction, will be discussed later.

In the Santa Cruz fauna, we have not the direct evidence that the Pampean faunæ afford for correlation by means of groups of admittedly northern origin. The evidence has been very fully discussed by Hatcher, Ortmann, Scott and others, and so far as it is based upon the relations and age of associated marine formations, I am not competent to criticize it. The criterion used by Ameghino and Roth, of proportions of extinct to living genera, I regard as untrustworthy, partly for the general reasons already given (p. 192) and partly because of the personal equation that must always affect the number of genera and species described as new, as compared with those referred to known genera and species. Unless the standards of diversity for genera and species were approximately the same, and in this instance they are certainly very wide apart,²⁶ the comparison of the proportions of extinct to surviving genera and species in Argentine formations with those of Europe or North America would be misleading.

Perhaps the most important correlation is that of the *Notostylops* fauna, Lower Cretaceous according to Ameghino, Upper Cretaceous according to Roth, Paleocene according to Gaudry, Upper Eocene in Schlosser's view. Here there is an apparently strong point for Cretaceous age in the presence of dinosaurs in association with the fossil mammals. Dinosaurs disappeared from the Northern world at the end of the Cretaceous.²⁷ They are entirely unknown in any Tertiary formation. Nevertheless, the possibility of their survival into the early Tertiary in South America must be considered.²⁸ The mammalian fauna with which

²⁶ The European fossil rodents are, for the most part, referred in accordance with the old conservative standards of genera and species, while Ameghino is much inclined to hairsplitting in generic and specific distinctions. Scott in his revision is more conservative, but not so as to equalize the standards in question.

²⁷ The latest dinosaur formations of North America are, however, regarded as Paleocene by Knowlton, Lee, Peale and other authorities.

²⁸ The same arguments apply to the occurrence of a Mesozoic type of Crocodile, *Notosuchus*, in the *Notostylops* fauna.

they are associated is in part closely related to the Paleocene fauna of Europe and North America and for this reason has been regarded as equivalent. But these genera of Northern affinities are associated with a large number of larger and more progressive genera, structurally derivable, according to the canons of evolutionary development universally accepted by paleontologists, from the more primitive types which are common to the *Notostylops* beds and the Paleocene of the North, and leading apparently into the various specialized groups peculiar to the later South American Tertiaries. These more progressive types are unknown to any northern Tertiary fauna; they appear to be derived from the more primitive group whose affinities are so close to the Puerco, Torrejon and Cernaysian mammals; and they point to the conclusion that the *Notostylops* fauna is in reality decidedly later than the Paleocene, the more primitive group of its fauna being little altered survivals,²⁹ corresponding to the primitive survivals (*Condylarthra*, etc.) which are found in the Wasatch and Wind River faunæ of North America. Taking the *Notostylops* fauna as a whole, it appears to me to represent an Eocene stage of development, conditioned by an isolation which began in the Paleocene and hence prevented the incoming of any *Perissodactyla*, *Artiodactyla* or *Carnivora* from North America.³⁰ This same isolation will satisfactorily account for a later survival of the dinosaurs, of Mesozoic *Crocodylia* and some other primitive elements, if they were in fact contemporary with the *Notostylops* fauna.

The age of the *Pyrotherium* beds is much less definitely determinable. Dr. Roth, indeed, doubts the existence of this fauna as distinct. If accepted, it would presumably be intermediate between the *Notostylops* and Santa Cruz faunæ and provisionally referable to the Oligocene.

The sequence of the Argentine faunæ will then be

Pampean (s. s.)	= Pleistocene
Monte Hermoso etc.	= Pliocene
Santa Cruz	= Miocene
Pyrotherium	= ? Oligocene
Notostylops	= Eocene.

So far as the correlation of the Pampean and Santa Cruz is concerned, their fossils agree wholly in preservation and degree of petrification with those preserved in similar Pleistocene and late Miocene formations, re-

²⁹ Little altered, that is to say, so far as the parts known to us are concerned; their adaptation, whatever it was, not involving radical changes in dentition from the primary type.

³⁰ Schlosser (in Zittel's *Grundzüge d. Pal.*, Rev. Ed. 1912) regards the *Notostylops* fauna as Upper Eocene. Scott (*History of Mammals of West. Hem.*) places it as Eocene.

spectively, in the western Plains, and the degree of consolidation of the matrix is the same. We have in the West two fossiliferous formations, the Bridger (Eocene) and John Day (Oligocene), which are, like the Santa Cruz, composed of an andesitic volcanic ash, and similar ash strata are found in different levels of our Western Miocene formations. Now, the Santa Cruz matrix and fossils are very much less consolidated or thoroughly petrified than the Bridger and decidedly less so than the John Day, while they agree very well with the volcanic ash beds in the middle and upper Miocene. As there is no reason to suppose that the rock-making processes work at a different rate in different continents, this evidence is entitled to some consideration. On similar grounds, the Pampean fossils would be referred to middle Pleistocene, and the few fossils that I have seen from Monte Hermoso agree best with Pliocene fossil mammals from North America. I should place no weight on this kind of evidence except when, as in the present instance, the climatic conditions and the origin and method of deposition of the formations are substantially similar.

The foregoing digression is somewhat outside the limits of this discussion. It appears, however, to be necessary to show briefly the reasons on which the age assigned to the South American mammalian faunæ are based. It might, indeed, be logically objected that these correlations are based on the northern origin and migration of certain phyla and cannot, therefore, be used in support of the theories here advocated. But the phyla on which the demonstration rests are so universally admitted to have arisen in the north, and the evidence that they did so is so complete and conclusive, that there is no reasonable alternate to accepting them as such. And if so, the correlations of South American faunæ must be approximately as here stated, a conclusion supported by the wholly independent evidence of the degree of consolidation of the formation and of petrification of the fossils contained.

CENTERS OF DISPERSAL

Whether the evolution of a race be regarded as conditioned wholly by the external environment or as partly or chiefly dependent upon (unknown) intrinsic factors, it is admitted by everyone that it did not appear and progress simultaneously and *aquo pede* over the whole surface of the earth, or even over the whole area of a great continent. The successive steps in the progress must appear first in some comparatively limited region, and from that region the new forms must spread out, displacing the old and driving them before them into more distant

regions. Whatever be the causes of evolution, we must expect them to act with maximum force in some one region; and so long as the evolution is progressing steadily in one direction, we should expect them to continue to act with maximum force in that region. This point then will be the center of dispersal of the race. At any given period, the most advanced and progressive species of the race will be those inhabiting that region; the most primitive and unprogressive species will be those remote from this center. The remoteness is, of course, not a matter of geographic distance but of inaccessibility to invasion, conditioned by the habitat and facilities for migration and dispersal.

If the environmental conditions in the center of dispersal pass the point of maximum advantage for the race-type that is being developed and become unfavorable to its progress, we should find its highest types arranged in a circle around a central region, which was the former point of dispersal, and the more primitive types arranged in concentric external circles. The central region will be unoccupied, or inhabited by specialized but not higher adaptations.

It would appear obvious that the present geographic distribution of a race must be interpreted in some such way as this by anyone who accepts the modern doctrine of evolution. Yet there are many high authorities on geographic distribution who proceed apparently upon a precisely opposite theory. According to these authors, the distribution center of a race is determined by the habitat of its most primitive species, and the highest and most specialized members of the race are most remote from its center of dispersal. This principle may be true enough so far as concerns the first appearance of a given race, *i. e.*, provided the most primitive species are also the oldest geologically; but it appears to me to be the direct reverse of fact as regards the present distribution, or the distribution at any one epoch of the past. The only ground on which it could be defended would be that the progress of the race is due to its migration, and those members which did not migrate did not progress. But this involves the view that its progressiveness up to the time that its geographical environment changed was due to staying at home, and the same progress after its environment changed was due to not staying at home. It seems to me that the prevalence of this view must be due to some fallacious notions about migration, unconsciously retained, involving a concept of it as analogous to travel in the individual. The successful business man, no doubt, may pack up his baggage and take to traveling, leaving home and going elsewhere and profiting much thereby. Nations have done the same thing, likewise to their advantage. But there is very little analogy here to the zoögeographic migration of spe-

cies—which is a question of expansion or contraction of range, not directly of transference of habitat, although this may be the final result.

It seems obvious that the conditions which brought about the early progressiveness of the race in a particular locality would, so far as they were external, cause the continued progressiveness of those individuals which remained in that region; so far as they were intrinsic, they would affect the main bulk of the race, the center of its range, more than any outlying parts of it. The present writer is very thoroughly convinced that the whole of evolutionary progress may be interpreted as a response to external stimuli; and intends here to point out what he regards as the most important of these stimuli. It is therefore necessary to point out that these postulates regarding centers of dispersal and migration are not dependent upon the theories to be proved—we are not reasoning in a circle.

OCEANIC AND CONTINENTAL ISLANDS

FAUNAL DIFFERENCES BETWEEN OCEANIC AND CONTINENTAL ISLANDS

One of the strongest arguments for the relative permanency of the deep oceans, especially during Cenozoic time, is afforded by the marked and striking contrast between the faunæ of those large islands which are, and those which are not, included within the continental shelf. The continental islands have the fauna of the continents to which they belong, large as well as small, differing only in the absence of types of recent evolution or of unsuitable adaptation and in the survival of primitive types which have disappeared from the mainland. But no question could be raised as to their former union with the mainland, no other possible solution would explain their fauna. We are compelled to assume the former connection of the British Isles with Europe, of Ceylon with India, of Japan with Korea or Siberia, of Sumatra, Java and Borneo with the Malayan mainland, of the Philippines with Borneo, of New Guinea and Tasmania with Australia, of Newfoundland and Cape Breton with Labrador and Nova Scotia. In each and all of these cases, the evidence is overwhelming, and, with the exceptions cited, the faunal identity is complete.

On the other hand, with all those islands which are separated by deep ocean from the mainland, we find that just that evidence is lacking which would afford convincing proof of former union with the mainland. Their faunæ are widely different from those of the adjoining mainland; they lack just those animals which could not possibly have reached there except by land bridges; they point often to long periods of independent evolution and expansion, and the primary elements of the faunæ of every

one of them are such as might possibly at least have reached the island without continental union, whether by accidental transportation, by swimming or by other means.

Take for example the mammals of Sumatra, Java and Borneo. We cannot reasonably suppose that the rhinoceroses, tapirs, deer, wild dogs, felids and numerous other large animals common to them and the adjoining continents reached these islands except by land. They are too large for transportation on "rafts" of vegetation such as occasionally drift to sea from the mouths of tropical rivers. They are dry-land animals not given to swimming long distances. And we would not invoke the agency of man to account for a whole fauna. But most important is the fact that all the animals that we might fairly expect to find there in view of a former land connection are really present.

Contrast with this the fauna of Madagascar.³¹ There are no ungulate mammals there, except for the bush-pig, possibly introduced by man (in accord with known customs of the Malays) and a pigmy hippopotamus (now extinct) which might have reached the island by swimming, as hippopotami are known to travel considerable distances by sea from one river mouth to another. The great majority of the ungulate groups of the mainland are also absent. The only representatives are a few very peculiar carnivores of the family Viverridæ, a peculiar group of insectivores (Centetidæ) and a peculiar group of Cricetine rodents, each apparently evolved on the island from a single type introduced long ago, a species of shrew (*Crocidura*) of more recent introduction and a variety of bats. There are numerous lemurs and no monkeys there; and the lemurs appear to have radiated out from a single group³² into a number of peculiar types, two of which, now extinct, paralleled the ungulates and the higher apes in several significant features. The fauna of the island does not resemble the present fauna of Africa, nor can it be derived from any one past fauna, known or inferential, of that continent. The attempt to derive it from the present or from any known or inferential past fauna of India involves still greater difficulties. On the contrary, the Malagasy mammals point to a number of colonizations of the island by single species of animals at different times and by several methods. Of these colonizations, the Centetidæ are the earliest, perhaps pre-Tertiary; the lemurs, rodents and viverrines are derivable from one or more middle Tertiary colonizations; and in both cases the "raft"

³¹ A. R. WALLACE: *Island Life*, pp. 381-412. 1881. See also Trouessart *Catalogus Mammalium* and *Suppl. Quinq.*; Lydekker, *Geog. Hist. Mam.*, pp. 211-226. 1896. Lydekker's arguments for continental union are mostly invalidated by more recent discoveries.

³² See W. K. Gregory's studies upon the affinities of the Lemuroidea, forthcoming in *Amer. Mus. Bulletin*.

hypothesis may reasonably be invoked.³³ The hippopotami may have arrived by swimming and the bush-pig and the shrew may have been introduced by man, while the bats may readily have arrived by flight. The extinct ground birds are easily derived from flying birds.

Dr. Arldt,³⁴ in his discussion of the Malagasy fauna, points out its composite character, derived from several successive invasions. This, I think, is clear enough; but it seems equally clear that these were not faunal invasions due to land connection but sporadic colonizations by a few species all at different times. The characters of the mammalian fauna, both negative and positive, practically exclude the theory of land connections during the Tertiary.

The West Indian islands afford another marked instance. In spite of its nearness to Florida, there are no North American mammals in Cuba, except the manatee,—analogous with the hippopotamus in Madagascar. Nor are the other islands richer in fauna. As also in Madagascar, we have a peculiar and very primitive insectivore *Solenodon* (Cuba and Hayti), a number of peculiar extinct ground-sloths, of which *Megalocnus* is the best known, and which although Pleistocene in age are derivable not from the Pliocene or Pleistocene ground-sloths of North or South America but from the Miocene ground-sloths of Patagonia, and evidently differentiated through a long-continued period of isolated evolution, and a couple of chinchillas—the hutias of the larger islands, the (extinct) *Amblyrhiza* in Anguilla. The *Solenodon* may be referred to a more ancient colonization, the ground-sloths probably arrived during the Miocene, the chinchillas more recently; and the direction of the prevalent ocean currents points out the reason why these are of South American derivation. Those who, like Dr. J. W. Spencer,³⁵ believe in gigantic elevation movements connecting the Antilles with the mainland in Pliocene and Pleistocene would account for the absence of the continental fauna by invoking a subsequent subsidence which drowned out everything else. The improbabilities involved in this hypothesis on stratigraphic and faunal grounds have been pointed out by W. H. Dall, R. T. Hill³⁶ and others.

³³ The moist tropical conditions of early Tertiary times would favor the formation of such rafts, the small size and arboreal habits of the animals concerned would increase the chances of their being caught on such rafts and the uniform climate and consequently more placid seas would increase the distance over which the raft might be transported before it broke up.

³⁴ THEODORE ARLDT: *Entwicklung der Kontinente und ihrer Lebewelt*, pp. 119-142. 1907.

³⁵ J. W. SPENCER: "Reconstruction of the Antillean Continent," *Bull. Geol. Soc. Amer.*, vol. vi, pp. 103-140. 1895.

³⁶ W. H. DALL: "Geological Results of the Study of the Tertiary Fauna of Florida," *Trans. Wagn. Inst.*, vol. iii, pt. vi. 1903.

R. T. HILL: "Geological History of the Isthmus of Panama and Portions of Costa Rica," *Bull. Mus. Comp. Zool.*, vol. xxviii, pp. 151-285. 1898.

Cuba, while near in actual distance to the North American continent, has been comparatively inaccessible to sporadic colonization from that source, on account of the direction of the ocean currents; but colonizations from South (or possibly Central) America have reached it. New Zealand is more remote and inaccessible, and, during the whole Mesozoic and Cenozoic eras, we have evidence of but two colonizations by land vertebrates, neither implying any necessary continental connection. The rock-lizard (*Sphenodon*) may, for aught we know to the contrary, be derived from a marine form; all its early Mesozoic relatives were aquatic, some apparently marine. The few other reptilia may be best accounted for by sporadic colonizations of later date. The moas are probably derivatives from flying birds.

When we come to the smaller oceanic islands, their poverty of fauna is still more conspicuous. If their fauna is due to sporadic colonization, this should be expected, as the chances are reduced directly in proportion to the smaller length of coastline on which an immigrant might land, as well as by their effective distance from the mainland. The colonization of a group of islands one from another may be due to former land connection and subsequent isolation, or to the same method of accidental transport, subject to the same laws of chance.

It is quite possible that in certain instances the small size and unfavorable environment of islands formerly connected with the continent may account for non-survival of the continental fauna. The Falkland Islands are a case in point; but even here, we find the survivors closely allied to the continental fauna and including types which afford the conclusive proof of continental connection which is uniformly lacking in oceanic islands.³⁷

The characteristics of continental and oceanic island faunæ have been very fully and ably elucidated by Wallace (*Island Life*), and it is intended here merely to assert that the progressive increase of our knowledge of the past life of the world tends only to emphasize the distinctions in the source of their faunæ which he has so clearly demonstrated and, so far as my acquaintance with the subject goes, to reduce still further the number of continental connections which he regarded as permissible.

To the argument so often advanced that the transportation of a species across a wide stretch of sea and its survival and success in colonizing a new country in this way is an exceedingly improbable accident, it may be answered that, if we multiply the almost infinitesimal chance of this

³⁷ Introduction of *Canis antarcticus* by human agency in prehistoric times is, however, a possible explanation of its occurrence. It is the only alternate to a Pleistocene land connection.

occurrence during the few centuries of scientific record by the almost infinite duration of geological epochs and periods, we obtain a finite and quite probable chance, which it is perfectly fair to invoke, where the evidence against land invasion is so strong. Furthermore, the fact that continents have not in general been peopled in this way one from another is well accounted for by the fact that species already existed there which filled the place in the environment and by their competition prevented the new form from obtaining a foothold, or greatly reduced the chances thereof. In oceanic islands, however, the favorable environment existed without the animal to fill it. Very often, on account of this lack, some other type was evolved to fill its place; birds being widely distributed on account of their powers of flight have in many oceanic islands developed large terrestrial adaptations to take the place of the absent or scanty mammals.

NATURAL RAFTS AND THE PROBABILITIES OF OVER-SEA MIGRATION THEREBY

The following series of facts and assumptions may serve to give some idea of the degree of probability that attaches to the hypothesis of over-sea transportation to account for the population of oceanic islands.

1) Natural rafts have been several times reported as seen over a hundred miles off the mouths of the great tropical rivers such as the Ganges, Amazon, Congo and Orinoco.²⁸ For one such raft observed, a hundred have probably drifted out that far unseen or unrecorded before breaking up.

2) The time of such observations covers about three centuries (I set aside the period of rare and occasional exploring voyages). The duration of Cenozoic time may be assumed at three million years (Walcott's estimate).

3) Living mammals have been occasionally observed in such records of natural rafts. Assume the chance of their occurrence (much greater than of their presence being noticed) at one in a hundred.

4) Three hundred miles drift would readily reach any of the larger oceanic islands except New Zealand. Assume as one in ten the probability that the raft drifted in such a direction as to reach dry land within three hundred miles.

5) In case such animals reached the island shores and the environment afforded them a favorable opening, the propagation of the race would require either two individuals of different sex or a gravid female. Assume the probability of any of the passengers surviving the dangers of landing as one in three (by being drawn in at the mouth of some tidal river or protected inlet), of landing at a point where the environment was sufficiently favorable as one in ten, the chances of two individuals of different sexes being together

²⁸ A recent number of the *Popular Science Monthly* (Sept., 1911, vol. lxxix, pp. 303-307) gives the recorded observations of the drift of a natural raft of this sort, covering over a thousand miles of travel.

might be assumed as one in ten, the alternate of a gravid female as one in five. The chance of one of the two happening would be $1/10 + 1/5 = 3/10$. The chance of the species obtaining a foothold would then be $3/10 \times 1/3 \times 1/10 =$ one in a hundred.

If then we allow that ten such cases of natural rafts far out at sea have been reported, we may concede that 1000 have probably occurred in three centuries and 30,000,000 during the Cenozoic. Of these rafts, only 3,000,000 will have had living mammals³⁹ upon them, of these only 30,000 will have reached land, and in only 300 of these cases will the species have established a foothold. This is quite sufficient to cover the dozen or two cases of Mammalia on the larger oceanic islands.

Few of these assumptions can be statistically verified. Yet I think that, on the whole, they do not overstate the probabilities in each case. They are intended only as a rough index of the degree of probability that attaches to the method, and to show that the populating of the oceanic islands through over-sea transportation, especially upon natural rafts, is not an explanation to be set aside as too unlikely for consideration.

I have considered the case only in relation to small mammals. With reptiles and invertebrates, the probabilities in the case vary widely in different groups, but in almost every instance they would be considerably greater than with mammals. The chance of transportation and survival would be larger and the geologic time limit in many instances much longer. Wind, birds, small floating drift and other methods of accidental transportation may have played a more important part with invertebrates, although they cannot be invoked to account for the distribution of vertebrates. The much larger variety and wider distribution of infra-mammalian life in oceanic islands is thus quite to be expected. And the extent and limits of such distribution are in obviously direct accord with the opportunities for over-sea transportation in different groups.

On the other hand, the transportation of very large animals in this way may fairly be regarded as a physical impossibility, which could not be multiplied into a probability by any duration of time. The only methods of accounting for such animals would be by evolution *in loco* from small ancestors, by swimming, by introduction through the agency of man and by actual continental union.

The first hypothesis would involve evolution in an isolated and more or less altered environment and would result in wide structural differences from any continental relatives. The second applies with greater probability to large than to small animals, but, except for animals of

³⁹ Small reptiles and invertebrates would only rarely be observed, if present.

more or less aquatic habits and within certain limits of distance, it is an apparent physical impossibility. The third may be either intentional or accidental and should be considered in connection with the known custom among Malays and other races, of taming various captured animals and taking them along on sea-voyages.¹ Its application is, of course, limited to distributional anomalies of late Pleistocene or modern origin. The last hypothesis, where it traverses the doctrine of the permanence of ocean basins, appears to me unnecessary, as I have failed to find a single instance of distribution which cannot reasonably be otherwise explained.

CONSIDERATIONS AFFECTING PROBABILITIES OF OVER-SEA MIGRATION IN SPECIAL CASES

The probabilities of over-sea transportation to an oceanic island will obviously be much greater if the island is large, and correspondingly reduced if it be of small size.¹ The distance from the mainland will greatly reduce the chances of such rafts making a landing, for two reasons: first, the chances of survival of the animals are reduced proportionately to the length of their journey (or rather, in a varying relation, which for convenience we may consider as a direct proportion): second, most rafts will be carried out from one or more points along the coast, but not from all points equally (that is to say, from the mouths of one or more great rivers, where the conditions are favorable, seldom from any of the small rivers). If we disregard prevalent winds and currents and consider the rafts as drifting out in all directions the probability of their landing on a given island will be directly proportioned to its length opposite the mainland, inversely to the distance. The probabilities of survival of animals, so far as it depends on the raft holding together, will also be inversely as the number of days exposure to the sea, hence as the distance. Comparing Saint Helena, 1100 miles from Africa and 10 miles diameter, with Madagascar, 200 miles from Africa and 1000 miles in length, we see that the probabilities of effecting a colonization would be $100 \times 3\frac{1}{2} \times 5\frac{1}{2}$, or 3025 times greater in the case of Madagascar. New Zealand, 800 miles long and 1200 miles from the Australian coast, will receive $\frac{8}{10} \times \frac{1}{6} \times \frac{1}{6}$, or $\frac{1}{45}$ as many colonizations as Madagascar, but $80 \times \frac{11}{12} \times \frac{11}{12}$ or 67 times as many as Saint Helena.

I believe that it is to their small size rather than to unfavorable conditions for survival that the poverty of fauna, especially of higher vertebrates, in the smaller oceanic islands is due.

The oceanic currents and prevalent winds do, of course, profoundly modify the above generalities in each individual instance. They have

prevented the populating of Cuba from North America, while facilitating invasions from South and Central America. The present set of currents reduces the probability of mammals reaching Madagascar from the African mainland, while increasing the chances of Oriental animals reaching it. It reduces materially the opportunities for Australian fauna to reach New Zealand.

We have no adequate data on which to base theories as to the former set of oceanic currents. A worldwide uniformity of climate would probably reduce the north and south movement of the waters; the east and west element of their motions is conditioned by the rotation of the earth, and its velocity would be reduced proportionately to the north and south movements; so that a more uniform climate would bring about a reduction of velocity rather than change in direction. The third principal conditioning element is the conformation of the continents, and doubtless the flooding of great areas and the opening up of broad though shallow passageways between seas now separated would profoundly modify the surface currents in many regions. The opening of a broad passage between North and South America would allow the Caribbean current to pass into the Pacific instead of being deflected northward and eastward along the shores of the Gulf of Mexico to find an outlet between Cuba and Florida. The absence of this initial part of the Gulf Stream would obviously be unfavorable to North or Central American animals reaching western Cuba. The great equatorial current would sweep across from Africa along the northern coast of South America, and uninterruptedly into the Pacific; transportation from Africa to South America or from South or Central America to the Galapagos Islands would thus be facilitated.

DISPERSAL OF MAMMALIA

MANKIND

We may with advantage begin our review of the special evidence in support of our theory with the migration history of man. This is the most recent great migration; it has profoundly affected zoögeographic conditions; it is the one where our data are most complete and accurate; we can perceive its causes and conditions most clearly, and we have a great deal of corroborative evidence in history and tradition.

All authorities are to-day agreed in placing the center of dispersal of the human race in Asia. Its more exact location may be differently interpreted, but the consensus of modern opinion would place it probably in or about the great plateau of central Asia. In this region, now barren

and sparsely inhabited, are the remains of civilizations perhaps more ancient than any of which we have record. Immediately around its borders lie the regions of the earliest recorded civilizations,—of Chaldea, Asia Minor and Egypt to the westward, of India to the south, of China to the east. From this region came the successive invasions which overflowed Europe in prehistoric, classical and mediæval times, each tribe pressing on the borders of those beyond it and in its turn being pressed on from

FIG. 6.—*Dispersal and distribution of the principal races of man*

No attempt is made to indicate anything beyond the broader lines of dispersal.

behind. The whole history of India is similar,—of successive invasions pouring down from the north. In the Chinese Empire, the invasions come from the west. In North America, the course of migration was from Alaska, spreading fan-wise to the south and southeast and continuing down along the flanks of the Cordilleras to the farthest extremity of South America. Owing to the facilities for southward migration afforded by the great Cordilleran ranges, the most remote parts of the New World are the forests of Brazil and of northeast South America. In the northern continent, Florida is the most distant from the source of migration.

In Africa, the region north of the Sahara has been overrun by successively higher types from the east. The great desert was a barrier to southward migration, being pierced only by the narrow strip of the Nile valley, from whose head spread out the successive populations of central and southern Africa. The main trend of migration followed the eastern highlands, the valleys of the Niger and Congo being more remote.

In the East Indies, the succession of great islands to the southeast, perhaps more connected formerly than now, formed stepping stones of migration to the distant continent of Australia.

The lowest and most primitive races of men are to be found in Australasia, in the remoter districts of southern India and Ceylon, in the Andaman Islands, in southwest and west central Africa and, as far as the New World is concerned, in northern Brazil. These are the regions most remote, so far as practicable travel-routes are concerned, from Central Asia. A century ago, the present habitat of primitive races was taken to be approximately the primeval home of man. With our present understanding of the conditions and causes of migration, a theory more in accord with tradition and history is generally accepted, and the dispersal center of man is regarded as situated in central or southern Asia. The influence of the old opinion is perhaps seen in the tendency to place this region south of the great Himalayan ridge and in tropical or semi-tropical climate.

This last assumption—that man is primarily adapted to a tropical climate—is, I think, only partly true at best. Its general acceptance is perhaps due, among other reasons, to the supposed relation between loss of hair on the body and the wearing of clothes, the first being regarded as an earlier specialization in an environment of tropical forests, the second as a secondary adaptation resulting from migration to a cold climate. But here, it seems to me, we are putting the cart before the horse. We may more reasonably regard the loss of hair in the human species as a result of wearing clothes and conditioned by this habit, rather than attribute it to any climatic conditions. This view is supported by several points in which the loss of hair in man is differentiated from the partial or complete loss of hair common in tropical animals, the following two being most clearly significant.

- 1) It is accompanied by an exceptional and progressive delicacy of skin, quite unsuited to travel in tropical forests. I do not know of any thin-haired or hairless tropical animal whose skin is not more or less thickened for protection against chafing, the attacks of insects, etc.

- 2) The loss is most complete on the back and abdomen. The arms and the legs and, in the male, the chest, retain hair much more persistently. This is

just what would naturally happen if the loss of hair were due to the wearing of clothes,—at first and for a long time, a skin thrown over the shoulders and tied around the waist. But if the loss of hair were conditioned by climate it should, as it invariably does among animals, disappear first on the under side of the body and the limbs and be retained longest on the back and shoulders.

It will not be questioned that the higher races of man are adapted to a cool-temperate climate, and to an environment rather of open grassy plains than of dense moist forests. In such conditions they reach their highest physical, mental and social attainments. In the tropical and especially in the moist tropical environment, the physique is poor, the death rate is high, it is difficult to work vigorously or continuously, and especial and unusual precautions are necessary for protection from diseases and enemies against which no natural immunity exists and which are absent from the colder and drier environment.

This lack of adaptation to tropical climate is also true, although to a less degree, of the lower races of man. Although from prolonged residence in tropical climate they have acquired a partial immunity from the environment so unfavorable to the newcomer, yet it is by no means complete. The most thoroughly acclimatized race—the negro—reaches his highest physical development not in the great equatorial forests but in the drier and cooler highlands of eastern Africa; and when transported to the temperate United States, the West Coast negro yet finds the environment a more favorable one than that to which his ancestors have been endeavoring for thousands of years to accustom themselves. In tropical South America, the Indians, as Bates long ago remarked, seem very imperfectly acclimatized and suffer severely from the hot moist weather; much more than the negroes, whose adaptation to tropical climate has been a much longer one.

In view of the data obtainable from historical record, from tradition, from the present geographical distribution of higher and lower races of men, from the physical and physiological adaptation of all and especially of the higher races, it seems fair to conclude that the center of dispersal of mankind in prehistoric times was central Asia north of the great Himalayan ranges, and that when by progressive aridity that region became desert it was transferred to the regions bordering it to the east, south and west. We may further assume that the environment in which man primarily evolved was not a moist or tropical climate, but a temperate and more or less arid one, progressively cold and dry during the course of his evolution. In this region and under these conditions, the race first attained a dominance which enabled it to spread out in successive waves of

migration to the most remote parts of the earth. The great mountain ranges to the south impeded migration in this direction, while to east and northeast, west and northwest, migration was easy and rapid. Reaching the New World by way of the Alaskan bridge, the long uninterrupted chain of the Cordilleras facilitated migration along their flanks to the farthest limits of South America.

There is little evidence if any, in the New World, of any migrations of inferior races long preceding those of the Amerind tribes, which would seem to have branched off at a moderately high stage in the evolution of mankind. *Per contra*, we find in South Africa, in Australia, in peninsular India and elsewhere, remnants of what must have been an early cycle of migrations. Each group of this early cycle, derived primarily from a different part of the central region of dispersal, has specialized further in proportion to its isolation and yet retains a predominance of the common primitive characters representing the stage of development attained when it left the dispersal center. The populating of Africa by the negroes may be regarded as the latest phase of this early cycle of dispersal, or should perhaps be considered independently.

The later development of the race is conditioned by its splitting in the region of dispersal into an eastern or Mongolian and a western or Caucasian stock. This split was presumably conditioned by the east-west elongation of the dispersal center caused by the facility of expansion in these directions and the mountain barriers to the south. All the eastward migrations from this time on bear a distinctly Mongolian stamp. An early phase of this stage is represented by the population of the New World and the variously mixed Malayan peoples. A later phase appears in the more typical Mongolian races. All the westward migrations, on the other hand, are of Caucasian affinities, this stock splitting, as the region of favorable environment widened out westward, into northeastern or Nordic, southwestern or Mediterranean groups. The peoples of northern Europe are derived from the successive migration waves of the first, those of southern Europe and northeast Africa from the second; the intermediate Alpine stock of central Europe is considered to represent a somewhat older migration allied to the Slavic peoples, who are to-day the principal population of eastern Europe, the latest cycle of Caucasian dispersal.

I have gone into this brief recital of the migration and dispersal history of mankind, not to present anything novel or authoritative, but because we have more evidence, direct and indirect, and more insight into the conditions and causes which controlled its course, than with any other

race of mammals. I believe that these controlling causes have been substantially the same in the lower animals as in man and their methods and routes of dispersal largely identical.⁴⁶

PRIMATES

We have seen that the dispersal center of man is in central Asia; that, in the present distribution, the survivors of the earliest cycle are found

FIG. 7.—*Dispersal of the Primates*

The marginal position of the modern lemurs, the progressive disappearance of the order from the more central regions which it formerly inhabited are clearly shown.

in Africa, peninsular India, the East Indies and Australia; that the populating of the New World belongs to a later cycle of distribution, and we have no good evidence that the earlier cycle ever reached it; that the dominant migration in the Old World has been east and west, progress to the south being hindered by the transverse mountain system to the south of which more primitive types long survived, while in the New World the dominant line of migration has been to the southward from Alaska, and eastward migration has been slower.

⁴⁶ One notes, too, the same fallacy in interpreting the data; some authors are disposed to place the center of dispersal of European races or languages in western Europe or in northern Africa because they find there the most primitive surviving races or languages.

In the living Primates we have survivors of pre-human stages in the evolution of man, specialized to a varying extent in different directions from him, so that they have not come into direct rivalry with him, and have hence survived.

The latest infra-human cycle is represented by the anthropoid apes, surviving to-day in the forests of West Africa and of the East Indies. We may suppose that these are remnants of a cycle of dispersal from a central Asiatic source, but we have no sufficient data to define its extent or time, except as late Tertiary and probably limited to Arctogæa. Nearest to man in intelligence and habits, this cycle has been swept out of existence, except for the few members which were or became adapted,

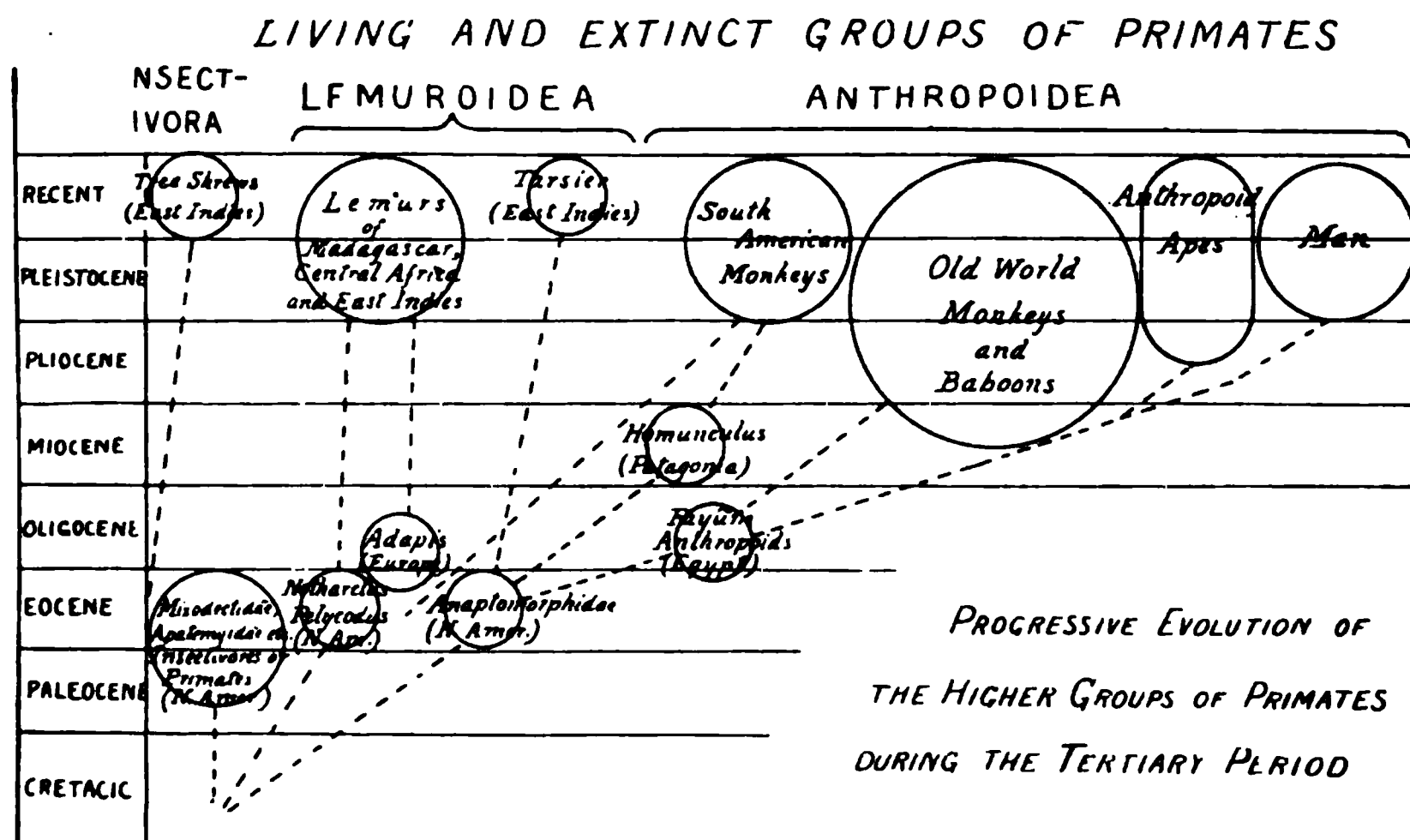


FIG. 8.—Phylogenetic relations of the living and extinct groups of Primates

The circles indicate the size and known geological range of the several groups, the dotted lines their most probable derivation. Their supposed relations to certain Insectivora and intermediate extinct groups are also indicated.

as our own ancestors were not, to tropical forest life. The arboreal habitat may be interpreted as a partial reversion. The doubtful and fragmentary remains of anthropoid apes in the Pliocene of Europe and of northern India are about all that the geological record has to state in regard to the former distribution of this cycle.

The next lower cycle is that of the monkeys and baboons of the Old World, and as a very doubtful early phase, the New World monkeys. The Old World monkeys inhabit most of Africa, India and the East Indies. To the northeast they extend to southern Japan. Closely related forms are found in the late Miocene of central and southern Eu-

rope, in the Pliocene of India, in the so-called Pliocene (which may be Miocene) of China. These may all be referred to a central Asiatic source. The dispersal of this cycle must date back at least to the beginning of the Oligocene, for it had reached as far as Egypt at the date of the Fayûm fauna as shown by Schlosser's recent discoveries.⁴¹ With the New World monkeys, the evidence seems rather to point to independent evolution in South America from early Tertiary Primates of an Eocene cycle of dispersal. For no remains of Primates have been discovered in any Oligocene or later formation in the United States, while the later Tertiary formations of the Argentine have yielded remains of a number of Primates apparently intermediate between Eocene lemurs and South American monkeys.

The oldest cycle of primate dispersal is that represented by the lemurs. These are now most abundant in Madagascar; a few exist in west and central Africa, peninsular India and the East Indies. Lemuroid primates, lacking certain specialized characters of modern lemurs but otherwise closely related, and equivalent in stage of development, are found abundantly in the Eocene of Europe and the United States. They are very doubtfully represented in the early Tertiary formations of the Argentine. We know too little of the Tertiary of other parts of the world to make any inference as to the extent of their distribution at that time, or the course of its subsequent changes. They disappear in Europe and North America at the end of the Eocene; in South America, they may have evolved into New World monkeys, while in the Old World they must have given rise to the higher primates. It is reasonably certain that the theater of their evolution was not Europe, and although they are not known in the Oligocene Fayûm fauna of Egypt, we may doubtfully suppose that they had reached that continent at some time during the Eocene. Madagascar most probably received its lemurs from Africa, but it is reasonable to suppose that only a single type, allied to the Eocene *Adapidæ*, reached the island, and in the favorable environment radiated out into a number of diverse adaptations taking the place of various mammal groups not present in the island fauna.

From the fact that the European and North American lemurs are in an equivalent stage of development, although not very closely related, we may fairly infer that they were derived very early in the Tertiary from an intermediate center of dispersal, presumably Asia north of the Himalayas.

⁴¹ MAX SCHLOSSER: "Beiträge zur Kenntniss der Oligozänen Landsäugethiere aus dem Fayûm Aegypten." *Beit. zur Pal. u. Geol. Oest.-Ung.*, B'd xxiv. s. 52. 1912.

CARNIVORA

The modern land Carnivora are spread over all the great continents except Australia, where a single species of wild dog, probably introduced by man, is their only representative. They are found equally in all the continental islands (*i. e.*, those included within the continental shelf border), and a few have reached Madagascar and other large oceanic islands.



FIG. 9.—*Distribution of the modern Canidae*

The jackals (Ethiopian and Oriental) are slightly more primitive than the true wolves and foxes; the Neotropical "Dog-foxes" more distinctly so. *Cyon*, *Icticyon* and *Lycyon* appear to be dispersed remnants of an aberrant group formerly Holarctic; the ancestry of the more typical Canidae is also found in Holarctica.

The order is unquestionably of Holarctic origin. Primitive Carnivora (Creodonta) are abundant in all the earlier Tertiary formations of Europe and North America, one group (Miacidae) ancestral to the higher Carnivora (Fissipedia), others which became extinct during the Oligocene. True fissipede Carnivora first appear in the Upper Eocene in Europe and North America and differentiate into the diverse modern types through the remainder of the Tertiary. They did not reach South

America until the Pliocene, their place being supplied up to that time by carnivorous marsupials. In Australia, their place is still taken by carnivorous marsupials. In Africa, primitive Carnivora (creodonta) appear in the Oligocene, represented only by the extinct family of hyænodonts, all of them derivable from Eocene hyænodonts of the Holarctic region; but the contemporary Holarctic Fissipedia had not yet reached Africa.

The modern land Carnivora are divided into seven families, each representing one or more broad phyla. The various divergent adaptations of the phyla and secondary re-adaptations of subphyla have brought about an amount of convergence and parallelism which makes it difficult to disentangle or to state accurately the true genetic relationship in any terms of classification. Some of the phyla are Holarctic, others Palæarctic or Nearctic. In all of them, we find the most primitive modern survivors in the tropical regions, the most advanced types in the Holarctic.

Canidæ.—The Canidæ are the most cosmopolitan family of the order. It is also the most progressive family in its adaptation to the open plains and arid climate of the great modern continents. The gradual adaptation of the race to these conditions from primitive arboreal forest-living ancestors can be traced through successive stages in the Tertiary formations of Europe and North America, but most completely in the latter country. The lengthening of the limbs and their adaptation for swift running, the reduction of the long balancing tail to a short comparatively unimportant organ, the perfection of the shearing and crushing teeth and, especially, the steady increase of brain capacity are the chief lines of progress. While most of the surviving Canidæ conform pretty closely to a single type, we find a tendency among their Tertiary ancestors to branch off on the one hand into more predaceous, on the other into more omnivorous types. Most of these have disappeared, but in the Oriental Ethiopian and Neotropical regions we find in the genera *Cyon*, *Icticyon* and *Lycaon* survivors of a more predaceous group which is known from the Oligocene and Miocene of the Holarctic region. This group has disappeared from Holarctica by the end of the Tertiary; two or three representatives are found in the Pleistocene of South America. Among the more typical modern dogs, the wolves and foxes are the most progressive types, the jackals slightly less so, the African fennec retains most nearly the primitive long tail, the South African *Otocyon*, while anomalous in possessing an extra molar tooth, is likewise normally primitive in several characters and the Neotropical “dog-foxes” show a marked resemblance in many details to the late Tertiary Canidæ of North America. The fact that the Canidæ are preëminently adapted to open country

and more or less arid climate is of primary importance in explaining their present dominance and cosmopolitanism, their close association with man, their absence from Madagascar and other oceanic islands; and it makes it most probable that the introduction of the dingo to Australia was through human agency although undoubtedly as early as the late Pleistocene. In their adaptation and distribution this family of Carnivora largely parallels the Equidæ among Perissodactyla.

TABLE II.—*Distribution of the Canidæ*

	Neotropical	Holarctic	Ethiopian	Oriental	Australian
Recent	<i>Canis</i> <i>Icticyon</i>	<i>Canis</i>	<i>Canis</i> <i>Lycaon</i> <i>Otocyon</i>	<i>Canis</i> <i>Cyon</i>	<i>Canis</i>
Pleistocene	<i>Canis</i> <i>Icticyon</i> <i>Dinocynops</i>	<i>Canis</i>	<i>Canis</i>	<i>Canis</i> <i>Cyon</i>	<i>Canis</i>
Pliocene	(?) <i>Amphicyon</i>	<i>Canis</i> <i>Dinocyon</i> , etc. <i>Cyon</i>	(Record inadequate)	<i>Canis</i> <i>Vulpes</i>	(No record)
Miocene	None	<i>Tephrocyon</i> <i>Amphicyoninæ</i> <i>Elurodon</i> <i>Cyon</i> , etc.	No record	<i>Amphicyon</i>	(No record)
Oligocene	None	<i>Cephalogale</i> <i>Cynodictis</i> <i>Daphænus</i> , etc. "Amphicyon"	None ^a	<i>Amphicyon</i> <i>Cephalogale</i>	(No record)
Eocene	None	<i>Cynodictis</i> , etc. <i>Cynoid</i> <i>Miacidæ</i>	(No record)		

^a Fayûm fauna, Egypt. Although this locality is not to-day within the Ethiopian province, its fossil mammals are generally regarded as representing the Ethiopian and not the Mediterranean fauna of the Oligocene. My own impression with regard to it is that it is transitional, as the Egyptian fauna is to-day, but dominantly Ethiopian instead of dominantly Mediterranean.

Procyonidæ.—The family Procyonidæ includes a member of omnivorous specializations from the central phylum now represented by the Canidæ. All of them are arboreal, partly retaining and partly reverting to the primitive mode of life in this respect. They are mainly Neotrop-

10

FIG. 10.—Distribution of the Procyonidæ and Viverridæ, formerly Neotrope and Palearctic, but now surviving chiefly in the peripheral regions

The geographical position of *Astur* is anomalous for a member of the Procyonidæ, to which family it is usually referred. Its true affinities, however, are doubtful.

ical, but the raccoon, the most dog-like of the family, survives as far north as the Sonoran region. The panda of the Himalayas is usually placed with Procyonidæ, but its true affinity is not very clear.

TABLE III.—*Distribution of the Procyonidæ*

	Neotropical	Holarctic	
		Sonoran	Palearctic
Recent	<i>Procyon</i> <i>Nasua</i> <i>Cercoleptes</i> <i>Bassaricyon</i> <i>Bassariscus</i>	<i>Procyon</i>	<i>Ælurus</i> (Affinities question- able)
Pleistocene	(Not recorded)	<i>Procyon</i>	
Pliocene	<i>Amphinasua</i> <i>Pachynasua</i> <i>Cyonasua</i>	<i>Probassariscus</i>	<i>Parailurus</i> (Affinities question- able)
Miocene	None	<i>Leptarctus</i> <i>Phlaocyon</i>	
Oligocene	None	<i>Cynodictis</i> (Probably ancestral in part)	
Eocene	None	Miacidæ	

Mustelidæ.—Primarily the Mustelidæ represent a more predaceous adaptation than the Canidæ. Their development through the Tertiary in the Holarctic region can be traced almost as completely as that of the dogs. Like the Canidæ (though not as early), they perfected during the later Tertiary a differentiation of the back teeth into shearing and crushing types, and they are equally progressive in brain development but much less so in running powers, retaining to a great extent their primitive forest-living habitat. They are to-day chiefly holarctic, the most progressive typical mustelids being the martens, weasels, ferrets and wolverenes. Early in the Tertiary there appear divergent side branches, specialized descendants of which survive to-day in the badgers, skunks and otters of the northern world, the intermediate forms being now extinct or confined to India and Africa.

Ursidæ.—The bears are regarded by many paleontologists as an offshoot from the Canidæ, but, on structural evidence, they appear to be related rather to the Mustelidæ. Their distribution indicates derivation

from a Palearctic source. The most primitive bears first appear in the Miocene of Europe; in the New World, they first appear in the Pleistocene. They are to-day chiefly Holarctic: the single South American species is distinctly primitive; the Oriental sun-bear and sloth-bear are partly aberrant, partly primitive. The Thibetan *Eluopus* is aberrant and specialized; its relation to the typical *Ursidæ* is not very close.

Viverridæ.—The Viverridæ are now almost exclusively Oriental and Ethiopian and have conserved the primitive type more than any other

FIG. 11.—*Distribution of the Ursidæ, Pleistocene and Recent*

The group appears to have dispersed from a Palearctic center, its Tertiary ancestral series being found in Europe and in the Miocene of India and China.

Carnivora, except some of the Procyonidæ which have a somewhat corresponding geographic position in the New World. The three most progressive genera, *Herpestes*, *Genetta* and *Viverra*, survive to-day along the southern borders of the Palearctic region; the remainder are Ethiopian or Oriental, the most primitive living genera being west African and East Indian. *Herpestes* and *Viverra* occur in the Oligocene and Miocene of Germany and France, and more primitive extinct genera in the Upper Eocene of Europe.

The primitive character of the viverrines is especially seen in their imperfect differentiation of shearing and crushing back teeth, their rather short limbs, long bodies, long tails and relatively small brain capacity.

Hyænidæ.—The family Hyænidæ is generally regarded as a specialized offshoot from the Viverridæ and is apparently connected with the European Miocene viverrids by a series of intermediate forms. The latest development of the race, the genus *Hyæna*, inhabited Europe and Central Asia and China in the Pliocene and Pleistocene but is now found only in India, Africa and southwestern Asia.

Felidæ.—The Felidæ are almost as cosmopolitan as the dogs and are even more uniform in type, the cheetah being the only marked living variant. A notably different specialization is shown in the extinct machærodonts or sabre-tooth tigers, and in the Tertiary sequence in Europe and America we find approximate genetic series, parallel in the two countries, by which the true cats and machærodonts converge towards a common primitive type, in which the upper canines are moderately elongated. According to this phylogeny, the clouded tiger of Sumatra and Java is the most primitive living felid, while the double series in Europe on one hand and North America on the other, would indicate northern Asia as the center of dispersal of the race. The range of some of the modern species is very great. The puma extends in the New World from Alaska to Patagonia, the tiger in the Old World from Manchuria to Java. We may note, however, that the tiger is regarded by Blanford as a recent immigrant into southern India; while, on the other hand, it is known that the northern range of the lion has been progressively restricted during prehistoric and historic times from northern Europe to its present limits of southwestern Asia and Africa.

PINNIPEDIA

When dealing with littoral and marine mammals we must expect to find the conditions of their evolution somewhat different. If the hypothesis be valid that the progressive refrigeration of the polar regions was the dominant cause of evolutionary progress and geographic dispersal, an examination of the map will show that the Arctic-North Atlantic basin affords the most favorable region. The Arctic basin centers around the pole, and a broad shelf of shallow water encircles it, extending as far south as latitude 45°. The North Pacific basin was closed to the northward by the Alaskan land-bridge during a large part if not all of the Tertiary, and its shores plunge suddenly to great depths, margined by

high mountains, affording less opportunity for expansional evolution of the littoral fauna. The Antarctic continent appears equally unfavorable, and dispersal from that center would also be hindered by the broad stretches of ocean.

We may expect, therefore, to find the littoral fauna of the North Atlantic most progressive, that of the North Pacific less so, the tropical faunæ containing many relict types of discontinuous distribution, and the Antarctic faunæ partly composed of types from the north which had crossed the barrier of warm water when the climatic zones were less differentiated than they now are; partly of groups developed in the south. Whether these groups were closely allied on the different southern continental shores would depend on their ability to cross the great barriers of deep ocean that separate them.

The distribution of the pinnipeds accords with these principles. The most specialized family is the Phocidæ, originating apparently in the Atlantic-Arctic basin, where *Phoca*, the most progressive genus, is found in the North Atlantic and Arctic seas and has penetrated into the North Pacific as far as California and Japan. Southward in the Atlantic it is succeeded by the less progressive *Monachus* in the Mediterranean and Antillean region. The Antarctic Phocidæ are also primitive and archaic, related more or less nearly to *Monachus*. In the Pliocene of Belgium are found extinct genera closely related to *Phoca* and others more primitive allied to *Monachus*.

The walruses, also Arctic and North Atlantic, have penetrated into the North Pacific only as far as Bering Sea; they are likewise recorded from the Pliocene of Northern Europe and along the North Atlantic in the Pleistocene as far south as Virginia.

The third family, the Otariidæ, is decidedly more primitive in structure, being less specialized for marine life. They are found in all the southern seas and on the North Pacific coasts. They are unknown to the North Atlantic and Arctic shores and have never been found fossil in either Europe or eastern North America. *Desmatophoca* and *Pontoleon* of the Miocene of Oregon are perhaps ancestral types, but more evidence is necessary before its North Pacific origin can be regarded as satisfactorily indicated.

INSECTIVORA

Among the Insectivora we deal with a number of very ancient races, whose relationship is much more distant than in many other mammalian orders. They are small, and most of the surviving members are scarce and little known, while they are still less known as fossils. So far as

we have any satisfactory evidence, the different races or most of them appear to have originated in the Holarctic region and spread to the southward. The most primitive division, the zalambdodonta, includes four families, the Centetidae of Madagascar, Chrysochloridae of South Africa, Potamogalidae of West Africa and Solenodontidae of Cuba. Fossil zalambdodonta are found in the late Miocene in South America, in the early Oligocene (and recently in the Basal Eocene) in North America. These indications are in conformity with the derivation of the group

FIG. 12.—Distribution of *Soricidae* (right to left shading) and of *Talpidae* (left to right shading)

The less specialized *Soricidae* are more widely dispersed, the highly specialized *Talpidae* limited to Holarctica. Ancestral types of both are found in the Tertiary of Europe and North America, but the evidence as to their phylogeny is very scanty.

from very ancient Holarctic ancestors, the modern zalambdodonta being the last surviving remnants of a dispersal from the north in early Tertiary or possibly pre-Tertiary times. But the evidence is too slight to be conclusive.

The hedgehogs are more clearly of Palearctic origin, the most primitive survivors being the East Indian *Gymnura* and *Hylomys*, while the most progressive genus, *Erinaceus*, is Palearctic and is preceded in the

Oligocene and Miocene of Europe by more primitive ancestral forms. A relatively primitive genus, *Proterix*, occurs in the Oligocene of South Dakota, as a contemporary with more progressive genera in the Oligocene of Europe. The family is otherwise unknown in the New World.

The moles and shrews are also evidently of northern origin. Of the two families, the Soricidæ are more primitive in structure and have spread more widely; the more specialized Talpidæ are still limited to Holarctica, and in the extreme north their exclusion from the areas of permanently frozen subsoil has split their range into two disconnected areas. The most progressive and abundant shrews are Holarctic, while the Oriental and African species (Crociturinæ) retain some primitive characters. Fossil moles and shrews in the middle Tertiary of Europe and America indicate that the divergence between the two families was not then so great as now. The modern genera are reported to occur (but on inadequate evidence) as early as the Miocene in Europe and America. Jaws of several minute talpoid genera are known from the Middle and Lower Eocene of North America. They are unknown in the extra-Holarctic Tertiary, but this negative evidence is of no weight in view of their minute size and rarity.

The Tupaiidæ of the East Indies and Macroscelididæ of Africa occupy a somewhat anomalous position, since they are of higher type in brain development than other Insectivora and in many respects are nearer to the higher placental mammals.⁴³ Their distribution so remote from the great northern dispersal center may perhaps best be accounted for by considering the fact that their specializations, adaptations and habits of life are of a less unusual kind than in most of the lower insectivores and would bring them more directly into rivalry with certain groups of rodents, with which they were unable to contend successfully and were compelled to retreat southward in consequence. No fossil remains certainly referable to these families are known, although quite a number of early Tertiary genera of Europe and North America have been or might be provisionally referred to them.⁴⁴

There are a large number of primitive Insectivora in the Eocene of North America and a few in Europe, which do not seem to be nearly ancestral to any modern group but rather indicate that the order once

⁴³ This anomaly in distribution is now removed by the studies of Gregory and Elliott Smith, which show that the true relations of *Tupaia* and presumably of *Macroscelides*, are with the Primates, rather than with the Insectivora. Their geographic distribution is quite normal on this view of their affinities.

⁴⁴ *Entomolestes* of the Middle Eocene of North America is regarded by Dr. Gregory as probably related to *Tupaia*, and a number of other small mammals from the Bridger and Wasatch may be related to this group of Insectivora.

took a much more important place in the mammalian faunæ of the world than it does now. This should be kept in mind in considering the relations of the Insectivora.

CHIROPTERA

I am not sufficiently acquainted with modern Chiroptera to venture an opinion as to whether or not their geographical distribution indicates their place of origin, but I should not expect to find much satisfactory evidence, as they are known to be of very ancient specialization and to have greater facilities for wide distribution than terrestrial animals.

Dr. Andersen,⁴⁵ in his recent Catalogue of the Chiroptera in the British Museum, remarks: "The evidence afforded by the geographical distribution of Bats has generally been considered of doubtful value; hence they have either been entirely excluded from the material worked out by zoögeographers, or at least treated with pronounced suspicion as likely to be more or less unreliable documents of evidence. This unwillingness or hesitation to place Bats on an equal zoögeographic footing with non-flying Mammalia would seem to be due partly to the preconceived idea that owing to their power of flight Bats must evidently have been able easily to spread across barriers which in ordinary circumstances are insuperable for wingless Mammalia; partly to the fact that hitherto very often whole series of distinct forms have been concealed under one technical name. . . ." [the author cites a series of instances of this kind which] "tend to show that the present distribution of the Megachiroptera has not been influenced to any great, and as a rule not to any appreciable extent by their power of flight; if it had the Fruit-bat fauna of islands could not so commonly as is actually the case differ from that of a neighboring group or continent, and the tendency to differentiation of insular species or forms would have been neutralized by the free intercourse between neighboring faunas."

The belief that bats are more easily able to cross ocean barriers than non-flying mammals is probably based, not on the preconceived idea that they could, but upon the plain fact that they have done so far more frequently. Birds and bats are found upon numerous oceanic islands where no non-flying mammals, and very few non-flying animals at all, exist. That they have wings and occasionally use them for so long a journey, whether voluntarily or involuntarily, is a natural explanation. I cannot see any other reasonable interpretation of the fact that they are present and the terrestrial mammals absent in so many remote oceanic

⁴⁵ K. ANDERSEN: Catalogue of the Chiroptera in the British Museum, Vol. I, Megachiroptera, p. lxxvi. 1912.

islands. With bats, as with most birds, the intervening ocean acts as a hindrance, but their wider distribution shows that it is less of a hindrance than with terrestrial mammals.

RODENTIA

The abundant and dominant order of Rodentia lends, in general, strong support to the theories here advocated; but there are certain serious difficulties which can be reconciled only by appealing to the imperfection of the geological record.

The rabbits and picas form a group apart, the former Nearctic, the latter Palæarctic since the Oligocene, and both Holarctic since the Pleistocene, the rabbits having extended their range over most of the Oriental region and a large part of the Ethiopian and Neotropical. A single specimen is recorded as from the Pleistocene of South America; their introduction to Australia is known to have been by civilized man.

Of the remaining rodents, the myomorph families are evidently of Holarctic origin, as they first appear in Europe and North America in the Oligocene and the highest and most progressive modern types (*e. g.*, Arvicolinæ) are now Holarctic, while in the southern continents they are unknown until the Pleistocene and various primitive survivals are found still living in Oriental, Ethiopian and Neotropical regions. We may note, however, that the very abundant and typical group of Cricetinae has its most primitive living representatives in tropical regions, that as we go south in South America, the genera approximate more toward the more specialized arvicoline type, in the same way that they do as we go northward in the northern continents.⁴⁶ Since there is no doubt that the cricetines are of northern origin, appearing first in South America in the Pliocene or Pleistocene, while they are common in the Holarctic regions from the Oligocene to the present day, we must suppose that the higher development of the Antarctic genera, to which Oldfield Thomas has called attention, is a case of parallelism with that of the Arctic genera and that the colder climate of the far south is the stimulus which reversed the usual conditions of geographical distribution. A review of the fauna of the Argentine as compared with that of tropical South America tends to show, I think, that this condition is general throughout, and that the fauna is more progressive and more nearly equivalent in development to those of the northern world than is that of the intervening tropical zone. This is equally true of autochthonic races and of those which are demonstrably of northern origin. Compare distribution of the

⁴⁶ OLDFIELD THOMAS.

genera of Procyonidæ, Canidæ, Cervidæ, Tatuidæ and Dasypodidæ among mammals.

Among the sciurormorphs, the squirrels are of early appearance (Oligocene) in the northern world but are now most abundant in the East Indies. The more specialized and later appearing marmots are chiefly Holarctic. The highly specialized beavers and pocket-gophers are Holarctic and Nearctic respectively, from their first appearance. A marked exception to the rule is seen in the survival in the western Sonoran sub-

FIG. 13.—*Distribution of Geomyoidea, Anomaluridæ and Pedetidæ*

The Geomyoidea are of Nearctic origin, but the more primitive Heteromyidæ have spread into part of South America. The Anomaluridæ are thought to be the nearest living relatives of the early Tertiary Theridomyidæ. The Pedetidæ are an aberrant specialization, derived perhaps from the same group.

region of *Aplodontia*, the most primitive living sciurormorph in several respects. I have no explanation to offer of this anomaly, save that we have not yet balanced properly the essential qualities of progressiveness among Rodentia.

Among the hystricomorphs, we find serious difficulties in the distribution. The most primitive living group is certainly the Anomaluridæ of West Africa; but, like the Pedetidæ of South Africa, they offer a

puzzling admixture of characters, which makes it doubtful whether they should be reckoned as pertaining to the same stock as the other hystricomorpha. The remaining families, while chiefly South American, are also partly represented in the Ethiopian, Oriental and Holarctic regions. It may be possible, in view of the facts that the European Theridomyidæ antedate geologically any specialized hystricomorphs, are apparently directly intermediate between the primitive rodent type (*Paramys* and its allies) and the hystricomorphs and show the early stages of differentiation of several hystricomorph families, that the Hystricomorpha are a

FIG. 14.—Distribution of the true porcupines (*Hystricidæ*) and New World porcupines (*Erethizontidæ*)

The Hystricidæ appear to be of Palearctic dispersal, the Erethizontidæ are apparently of Neotropical origin.

group of Holarctic origin which has spread into all the southern continents and specialized independently on parallel lines. But their entire absence from the recorded North American Tertiary is then explainable only by the defective record, and our knowledge of North American Tertiary rodents is so extensive that I should hardly regard this assumption as justifiable. The fact that the highest and most specialized types are South American necessarily involves the idea that that continent has been the most important center of their later development and dispersal,

and the alliance of the African to the South American genera and of the New and Old World porcupines must be regarded as more remote than it appears. Dispersal from South America by help of Antarctic or transatlantic land-bridges will not solve the problems of their distribution much better. The most specialized porcupines in most respects are the hystricids of the Old World—late Tertiary in Europe, now chiefly Oriental and African. The Nearctic porcupines (*Erethizon*) are more advanced in several features than the Neotropical (*Synetheres*). Yet the ancestors of the New World porcupines at least occur in the late Tertiary of South America and are absent or unrecorded from the Tertiary of North America. The distribution of the Octodontidæ in Africa and South America would possibly admit of being interpreted by parallel development from theridomyid ancestors; but the parallelism must have been singularly close, and the absence or non-recognition of Theridomyidæ from the North American Tertiaries appears surprising. I have been unable to frame any hypothesis which will fit all the facts of distribution in this group,⁴⁷ except by assuming that the South American Hystricomorpha, which as Scott has shown are all clearly derived from a single stock, reached South America from Africa in the Oligocene by over-sea raft transportation. This involves so long a voyage that I hesitate to accept it as a reasonable probability, even though the winds and currents would obviously favor transportation in this direction.

The Hystricidæ may fairly be assumed as of Old World origin, and probably Palæarctic, since they are represented in the later Tertiary of Europe and are unknown in the New World. The Erethizontidæ must apparently be derived from South America, since they are unknown in the Old World, and unknown in the North American Tertiary, while *Steiromys* of the Patagonian Miocene appears to be ancestral.

The primary type of the simplicidentate rodents, as I have elsewhere shown,⁴⁸ must be regarded as being represented by the Ischyromyidæ of the American and European Eocene, in particular by *Paramys* and *Sciuravus*. All other rodents may be derived from this group by divergent, parallel and in some respects convergent evolution. Modern rodents represent a great number of independent derivations from this primary stock, their association into sections and families being to a considerable extent artificial.

⁴⁷ The hypothesis of migration to or from South America across a land-bridge from Africa to Brazil is equally unsatisfactory as an attempt to explain the relations of the hystricomorph families and is entirely at variance with the evolution and distribution of other mammalian orders, besides being highly improbable on isostatic grounds. The supposed evidence in its favor from lower vertebrates and invertebrates is due, so far as I have been able to examine it, to a lack of appreciation of the principles of dispersal of races and of parallelism and of the imperfection of the geological record.

⁴⁸ "Osteology and Relationship of *Paramys* and Affinities of the Ischyromyidæ," Bull. Am. Mus. Nat. Hist., vol. xxviii, p. 43-71. 1910.

There are no rodents in the *Notostylops* Beds of South America (Eocene); presumably therefore none in preceding epochs. There are none in the Paleocene of Europe and North America; presumably therefore their sudden appearance in the true Eocene of these regions was due to migration from some other region, equidistant from either, as their development is almost equivalent in the two,—therefore probably Asia. The few Theridomyidæ of the Oligocene of Africa are rather primitive forms, certainly not more progressive than their contemporary relatives

FIG. 15.—Distribution of the Neotropical families of Hystricomorpha

The Octodontidæ are also found in Africa, and the Theridomyidæ of the early Tertiary of Europe are apparently ancestral to these families of the Hystricomorpha. No hypothesis satisfactorily explains the accepted relationship and distribution.

in Europe, affording thus a slight indication that they were Palearctic immigrants. In Australia the evolution of Marsupial analogues of the more abundant rodent types of *Arctogæa* affords strong evidence that the true rodents were absent from *Notogæa* until the end of the Tertiary; a view confirmed by the limited amount of adaptive radiation which the invading Muridæ have undergone in that continent up to the present day.

The Australian Muridæ can only be accounted for by over-sea transportation, for the family appeared and evolved during the middle and later Tertiary, and the peculiarities of the Australian fauna are explained by all writers as due to isolation extending through the Tertiary period.

TABLE IV.—*Distribution of the Rodents*

	S. America	N. America	Asia	Europe	Africa	Australia
Recent	Muridæ and Hystri- comorpha Lagomor- pha	Myomor- pha Sciuromor- pha Lagomor- pha <i>Erethizon</i>	Myomor- pha Sciuromor- pha Lagomor- pha Hystri- cidæ (Ori.)	Myomor- pha Sciuromor- pha Lagomor- pha	Myomor- pha Sciuromor- pha Hystri- comorpha	Muridæ
Pleisto- cene	Hystri- comorpha and Muridæ Lagomor- pha	Myomor- pha Sciuromor- pha Lagomor- pha <i>Erethizon</i>	Myomor- pha Sciuromor- pha Lagomor- pha Hystri- cidæ	Myomor- pha Sciuromor- pha Lagomor- pha Hystri- cidæ	?	?
Pliocene	Hystri- comorpha	Sciuromor- pha Myomor- pha Leporidæ	Myomor- pha Leporidæ? Hystri- cidæ	Myomor- pha Sciuromor- pha Ochotonidæ Hystri- cidæ	?	
Miocene	} Hystri- comorpha	Sciuromor- pha Myomor- pha Leporidæ	?	Sciuromor- pha Myomor- pha Ochotonidæ	?	
Oligocene	Cephalo- mys ⁴⁹	Sciuromor- pha Myomor- pha Leporidæ Ischyromy- idæ	?	Sciuromor- pha Myomor- pha Ochotonidæ Therido- myidæ	} Therido- myidæ	
Eocene	None	{ Ischyro- myidæ	?	{ Therido- myidæ Ischyro- myidæ	?	
Paleocene		None	?	None		
Cretace- ous		None	?	None		

⁴⁹ A hystricomorph, recorded by Ameghino from the *Pyrotherium* beds.

PERISSODACTYLA

The order Perissodactyla is represented to-day by three widely separated families—the rhinoceroses, Ethiopian and Oriental; the tapirs, Neotropical and Oriental, and the horses, Asiatic and Ethiopian. The last group is the most progressive and modernized, but the whole order must be regarded as having seen its best days and as passing towards extinction in competition with the better organized and more adaptable

FIG. 16.—*Diapervul and distribution of the Perissodactyla*

The tapirs are on the whole the most primitive and their present distribution widely discontinuous. The rhinoceroses are less widely dispersed and the horses the most central in their present distribution. All were inhabitants of Tertiary Holarctica, but their diapervul centers appear to have been Palearctic, as indicated.

Artiodactyla. The geological record affords abundant evidence of the Holarctic origin of all the Perissodactyla. The ancestry of each race can be traced back in the Tertiary faunæ of Europe and the United States, in a series of approximately ancestral stages, sometimes closer in one region, sometimes in the other, to a group of closely allied primitive perissodactyls in the early Eocene of both countries. In South America, the order is unknown until the late Pliocene and Pleistocene. In other re-

gions we know too little of the early Tertiary faunæ to say when the perissodactyls first appeared, but they are absent from the Oligocene fauna of Egypt, from the Pleistocene and modern faunæ of Australia and of all oceanic islands. This accords with the natural inference from their size, proportions and habits that they would be strictly limited by land connection in their geographic distribution.

Besides the surviving groups, the early perissodactyls gave rise to several extinct families, the lophiodonts, palæotheres, titanotheres and chali-

FIG. 17.—Distribution of *Equidae*, living (solid black) and Pleistocene (shaded)

Early Tertiary ancestors are found in Nearctic and Palearctic regions. The American series is more direct than that of Europe until the late Tertiary. This and other considerations indicate the center of dispersal as in northeastern Asia or northwestern North America.

cotheres, none of which are known to have invaded the southern continents.

Equida.—The best known phylum of the order, that of the horses, is certainly not a direct genetic succession, as regards known species, but approximately so as regards the known genera. The successive genera are progressively more specialized in accordance with their geological

sequence. They are identical or closely allied in the European and North American sequence. In North America, the series is more complete, the approximation to a direct genetic sequence is closer and the successive stages appear earlier in time. This is reasonably interpreted by supposing that the center of dispersal was intermediate between Europe and the western United States but nearer to the latter. That is to say, it was either in boreal North America or in northeastern Asia. The absence of

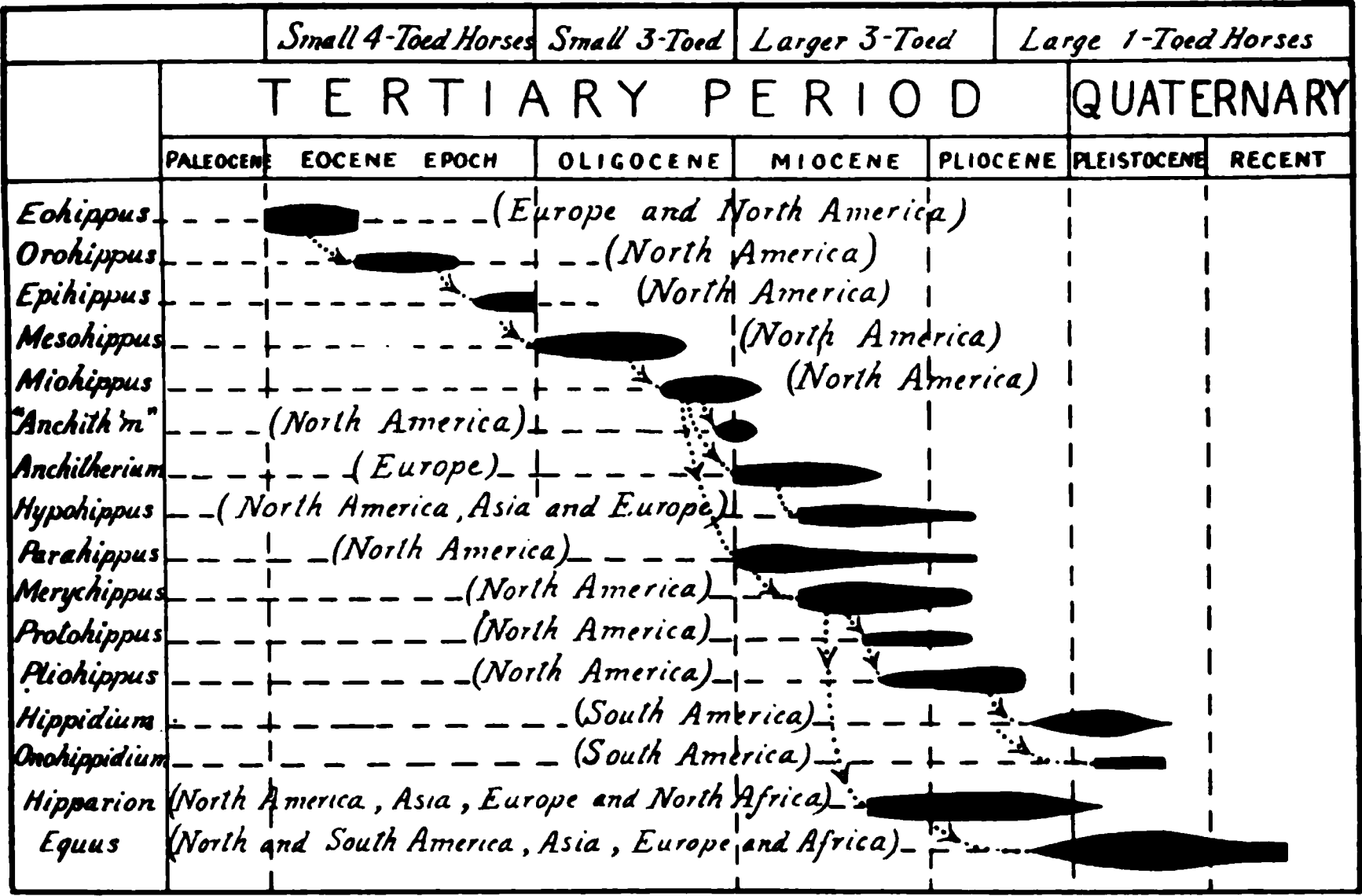


FIG. 18.—Geologic range and phylogenetic relations of fossil Equidae

The overlap in geologic range of the genera, and the sudden appearance of each new stage, indicate that our record is not derived from the center of dispersal of the race; although the American series is sufficiently direct to indicate that it was not very remote.

primitive survivors of the race in the East Indies is natural; as the horses were very early adapted to open plains, unfitted for mountain or forest habitat, the great transverse Himalayan chain would form an almost impassable barrier and the heavily forested regions of the East Indies would have no attractions to tempt the ancestral horses to pass around its eastern end.

TABLE V.—Distribution of the Equidae

	Neotropical	Nearctic	Palaearctic	Oriental	Ethiopian
Recent			<i>Equus</i>	<i>Equus</i>	<i>Equus</i>
Pleistocene	<i>Equus</i> <i>Hippidion</i> <i>Onohippidion</i> , etc.	<i>Equus</i> ? <i>Hipparion</i>	<i>Equus</i>	<i>Equus</i> (India)	<i>Equus</i>
Pliocene	—	<i>Hipparion</i> <i>Pliohippus</i> <i>Protohippus</i> <i>Merychippus</i> <i>Parahippus</i> <i>Hypohippus</i>	<i>Equus</i> <i>Hipparion</i> <i>Hypohippus</i>	? <i>Equus</i> (Siwalik) <i>Hipparion</i>	
Miocene	—	<div><div><i>Hipparion</i> <i>Pliohippus</i> <i>Protohippus</i> <i>Merychippus</i> <i>Hypohippus</i></div><div><i>Merychippus</i> <i>Hypohippus</i> <i>Parahippus</i></div><div><i>Parahippus</i></div></div>	<i>Hipparion</i> <i>Anchitherium</i> <i>Anchitherium</i>	<i>Hipparion</i> (L's Siwalik)	
Oligocene	—	<i>Miohippus</i> <i>Mesohippus</i>			—
Eocene	—	<i>Epihippus</i> <i>Orohippus</i> <i>Eohippus</i>	<div><i>Anchilophus</i> <i>Lophiotherium</i></div> <i>Pachynolophus</i> <i>Hyracotherium</i>		

Tapirida.—The tapirs are the most primitive living perissodactyle, retaining the primitive number of digits in fore and hind feet and the primitive short-crowned grinding teeth. They are to-day limited to the East Indies and tropical America. In the Pleistocene, they inhabited the Sonoran region and continental India and the marginal parts of the Palearctic region. Their Tertiary ancestry has been traced back in Europe and in North America to the Oligocene *Protapirus*, which is preceded by a less direct ancestral series in the Eocene of North America;

FIG. 10.—Distribution of the Tapirs living (solid black) and Pleistocene (shaded)

Ancestral types are found in the Tertiary formations of Europe and North America. The relations of the two series and the Pleistocene and modern distribution indicate a dispersal center in eastern Asia.

but ancestral tapirs have not been identified in the Eocene of Europe. The data are insufficient to determine the center of dispersal except as probably in the Palearctic region. Tapirs are unknown in South America until the Pampean (Pleistocene); they do not appear to have reached Africa at all. The arid climate of the Afro-Asiatic connection and the heavily forested path of migration to the East Indies would seem to be the features that determined the dispersal of the horses into Africa, the tapirs into Malaysia.

TABLE

of the *Tapiridae*

²⁰ True affinities of these genera

²¹ Affinities between tapira and rhinoceroses.

2

4

FIG. 20.—Distribution of the *Rhinoceroses*, *Heing* (solid black) and *Pleistocone* (shaded)

Primitive rhinoceroses are found in the Palearctic and Nearctic Tertiaries and late Tertiary of India and Africa. Comparison of the Palearctic and Nearctic series indicates that the center of dispersal was in west-central or southwestern Asia.

Rhinocerotidæ.—The rhinoceroses are intermediate between horses and tapirs in adaptation. The Tertiary history of the group is much the same, approximate series being found in Europe and North America as far back as the Oligocene or Eocene, but the phyla are less direct and complete, and there is a greater diversity of type among them. The Palæarctic series appear to be more direct, and this, in connection with the fact that the race never reached South America, may be taken to indicate that the center of dispersal was Palæarctic rather than Nearctic, less northerly than that of the horses, less easterly than that of the tapirs. At all events, the relations of the later Tertiary rhinoceroses indicate that North America was much more remote from the center of dispersal than Europe, while southwestern Asia was very close to it.

TABLE VII.—*Distribution of Rhinoceroses*

	Nearctic	Palæarctic	Oriental	Ethiopian
Recent	None	None	<i>Rhinoceros</i> <i>Ceratorhinus</i>	<i>Cælodonta</i> <i>Opsiceros</i>
Pleistocene	None	<i>Elasmotherium</i> <i>Cælodonta</i> <i>Opsiceros</i> <i>Ceratorhinus</i>	<i>Rhinoceros</i> <i>Opsiceros</i>	<i>Opsiceros</i>
Pliocene	<i>Teleoceras</i>	<i>Opsiceros</i> <i>Ceratorhinus</i> <i>Teleoceras</i>	<i>Rhinoceros</i> <i>Teleoceras</i> <i>Aceratherium</i>	?
Miocene	<i>Teleoceras</i> <i>Aphelops</i> <i>Diceratherium</i>	<i>Teleoceras</i> <i>Aceratherium</i> <i>Diceratherium</i>	Rhinoceroses	Rhinoceroses
Oligocene	<i>Cænopus</i> <i>Trigonias</i> <i>Metamynodon</i> <i>Hyracodon</i>	<i>Cænopus</i> ⁵² <i>Prohyracodon</i>	<i>Aceratherium</i> ⁵⁴ <i>Diceratherium</i> <i>Teleoceras</i> <i>Cadurcotherium</i>	No Perissodactyla
Eocene	<i>Amynodon</i> <i>Triplopus</i> Lophiodontidæ ⁵³		?	

⁵² Includes a number of subgenera recently defined by Abel.

⁵³ This family may be regarded as ancestral to both rhinoceroses and tapirs, but the more exact derivation is doubtful.

⁵⁴ Gaj fauna, upper Aquitanian auct. Pilgrim. It should perhaps be regarded as Lower Miocene.

ARTIODACTYLA

The great and diverse order of artiodactyla can fairly be regarded as of Holarctic origin as a whole. Its distribution can most readily be considered group by group.

Pigs and Peccaries.—These two groups are characteristic of the Old and New World respectively. The pigs are now chiefly Ethiopian and Oriental, the peccaries Neotropical in distribution. The peccaries first reached South America in the Pleistocene and ranged throughout the

FIG. 21.—Distribution of pigs and peccaries

In Old World, broken shading *Sus* only; full shading, other genera. In New World, full shading *Dicotyles*. The dispersal center of Dicotylids was Nearctic, of Suidæ Palearctic. The living South American genus is more primitive than the Pleistocene genera of North America, *Platygonus* and *Mylodon* (the Pleistocene North American species referred to *Dicotyles* are all *Mylodon*).

United States from the Oligocene to as late as the Pleistocene. Pigs were common in the Oligocene and later Tertiary in Europe and were present in India in the Miocene, probably earlier. The Tertiary ancestry of the pigs in Europe can be traced back to a common ancestral group in the Eocene, and the same is true of the peccaries in the western United States.

TABLE VIII.—*Distribution of the Pigs and Peccaries*

	Neotropical	Nearctic	Palæarctic	Ethiopian	Oriental
Recent	<i>Dicotyles</i>		<i>Sus</i>	<i>Potamochoerus</i> <i>Phacochoerus</i>	<i>Sus</i> <i>Babirusa</i>
Pleistocene	<i>Dicotyles</i>	? <i>Dicotyles</i> <i>Mylohyus</i> <i>Platygonus</i>	<i>Sus</i>		.
Pliocene	? <i>Platygonus</i> ? <i>Prosthennops</i>	<i>Platygonus</i>	<i>Sus</i>		<i>Sus</i> , <i>Hippohyus</i> <i>Samitherium</i> <i>Potamochoerus</i>
Miocene	None	<i>Prosthennops</i> <i>Desmathyus</i>	<i>Sus</i> <i>Listriodon</i> etc.	(No record)	<i>Listriodon</i> ? <i>Sus</i> , <i>Hippohyus</i> <i>Potamochoerus</i> <i>Hyotherium</i> <i>Palæochoerus</i>
Oligocene	None	<i>Perchoerus</i>	<i>Palæochoerus</i> <i>Hyotherium</i> etc.	None ⁵⁵	<i>Palæochoerus</i> ⁵⁶
Eocene	None	? <i>Helohyus</i> etc.	<i>Cebochoerus</i> etc.	(No record)	

Ruminants.—Under this term, we may conveniently include all the selenodont artiodactyls,—the camels and tragulines, deer, antelopes, sheep and cattle, besides various extinct groups.

They are admittedly of Northern origin. In South America, they do not appear until the end of the Tertiary (*Microtragulus*, Monte Hermoso); their representatives in the Oligocene of North Africa are much more primitive than the contemporary artiodactyls of Europe; the highest and most progressive types are found to-day in Asia, and the most antique and primitive survivals in the East Indies, West Africa and tropical America. The several groups indicate in their present distribution, and in what is known of their past history, that their centers of dispersal

⁵⁵ Schlosser has shown that *Gentohyus* is a Hyracoid, not an Artiodactyl.

⁵⁶ Gaj fauna, regarded by Pilgrim as upper Aquitanian.

were in different parts of the northern world, as we have seen among the Perissodactyl groups.

The camels appear to have been of American origin. An ancestral series is found in the Tertiary of the western United States, going as far back as the Upper Eocene.⁶⁷ In the Old World, they first appear in the Pliocene; in South America, in the Pleistocene (Pampean); and the

FIG. 22. —*The dispersal center of the Camelidae was in North America*

They reached the Old World in the Pliocene, South America in the Pleistocene. They survive on the margins of their range but became extinct in North America early in the Pleistocene. North American Pleistocene camels were more advanced than the living types of the marginal areas.

camels of the Pleistocene in North America were about as specialized on the whole as the living llamas of South America or the camels of Africa and Asia. In North America, the race is now extinct. The center of dispersal would appear to have been in this continent,—how far to the north we have no means of estimating; but the exceptional directness of the phylogenetic series as represented by our western fossils indicates, in my opinion, that these fossils lived in or close to the racial dispersal center.

⁶⁷ It forms a singularly direct and complete phylum, so supercharged with intermediate and connecting forms that it is very difficult to classify and arrange the fossils into species and genera, while every gradation of structural evolution is abundantly illustrated.

TABLE IX.—*Distribution of the Camels*

	Neotropical	Nearctic	Palaearctic	Ethiopian	Oriental
Recent	<i>Auchenia</i>	None	<i>Camelus</i>	None	None
Pleistocene	<i>Auchenia</i>	<i>Eschatius</i> <i>Camelops</i> <i>Camelus</i>	<i>Camelus</i> ? <i>Procam-</i> <i>elus</i> ³⁸	?	<i>Camelus</i>
Pliocene	None	<i>Pliuchenia</i> etc.	? <i>Paracam-</i> <i>elus</i> ³⁹	(No record)	? <i>Camelus</i> ⁴⁰
Miocene	None	<i>Procamelus</i> <i>Protolabis</i> <i>Miolabis</i> etc. <i>Oxydactylus</i>	None		None
Oligocene	None	<i>Protomeryx</i> etc. <i>Poebrotherium</i> <i>Eotylopus</i>	None	None	(No record)
Eocene	None	<i>Protylopus</i>	None	(No record)	

The tragulines, recent and extinct, are a heterogeneous assemblage of primitive ruminants, whose real affinities have been much disputed. In the present writer's opinion, the living East Indian chevrotains should be associated with *Hypertragulus* of the North American Oligocene and perhaps *Microtragulus* of the South American Pliocene, and the center of distribution of this group hypothetically placed along the northeastern coast region of Asia (cf. tapirs). The living water-chevrotain (*Hyamochus*) and most of the so-called tragulines of the European Oligocene and Upper Eocene are to be regarded as primitive stages of true Pecora. *Leptomeryx*, *Protoceras* and *Heteromeryx* are related forms from the North American Oligocene. Among these primitive forms, some (*Leptomeryx*) display affinities to the deer, others (*Protoceras*, *Heteromeryx*) to giraffes and antelopes.

³⁸ *C. stralensis* of the Siwalik beds is doubtfully congeneric with the modern species and, along with the so-called *Procamelus* described by Mme. Pavlow from the Pleistocene of Russia, appears to be an intermediate stage between *Procamelus* and *Camelus*.

⁴⁰ A doubtful Camelid, based on a single upper molar from the Pliocene (or Miocene) of China.

In the later Oligocene of Europe and the Miocene of the United States appear more definitely deer-like types (*Dremotherium*, *Blastomeryx*), and in the succeeding formations we find progressively higher types of deer in Europe and North America, but always appearing earlier in the Old World. The deer—excepting the isolated primitive survival represented by the “water-chevrotain,” closely related to *Dorcatherium*, a Miocene genus in Europe—have not reached the Ethiopian region, but

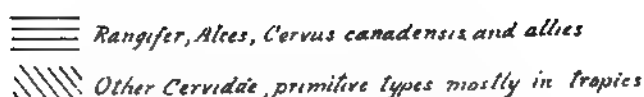


FIG. 23.—Distribution of Cervidae and pro-Cervid Tragulidae

The highest and latest appearing types are still confined to the circum-Arctic regions; the genera of the more peripheral regions are more primitive. The earliest and most direct ancestral series is found in Europe and Asia; the parallel series in North America is less direct and more retarded. A primitive survival is found in West Africa, protected by the desert from competition of higher types.

were easily able to reach North America in the Pleistocene. I take it, therefore, that their center of dispersal was well to the east and north in Asia (*cf.* horses). Their migration into the Ethiopian region was checked after the Miocene by the progressive aridity of the desert region between,

which served as a barrier to these forest-living ruminants, although not to the plains-living antelopes.

TABLE X.—*Distribution of Tragulidæ proper*

	Neotropical	Nearctic	Palæarctic	Ethiopian	Oriental
Recent	None	None	None	None	Tragulus
Pleistocene	None	None	None	None	Tragulus
Pliocene	?? Microtrag- ulus	None	None		Tragulus
Miocene	None	None	? None		None
Oligocene	None	[Hypertrag- ulus]	? None	None	None
Eocene	None	[Primitive Artiodactyla]			

TABLE XI.—*Distribution of Cervidæ and Pro-Cervid Tragulines*

	Neotropical	Nearctic	Palæarctic	Ethiopian	Oriental
Recent	<i>Odocoileus</i> <i>Mazama</i>	<i>Cervus</i> , <i>Alces</i> <i>Rangifer</i> <i>Odocoileus</i>	<i>Cervus</i> , <i>Alces</i> <i>Rangifer</i> , <i>Dama</i>	<i>Hyæmos- chus</i> (W. Afri- ca) ⁶¹	<i>Cervus</i> (<i>sensu lato</i>)
Pleistocene	<i>Odocoileus</i> <i>Mazama</i>	<i>Cervus</i> , <i>Alces</i> <i>Rangifer</i> <i>Odocoileus</i>	<i>Cervus</i> , <i>Alces</i> <i>Rangifer</i> , <i>Dama</i> <i>Megaceros</i>		<i>Cervus</i> (s. l.)
Pliocene	None	<i>Cervus</i> (s. l.)	<i>Cervus</i> (s. l.) etc.	(No record)	<i>Cervus</i> (s. l.) <i>Moschus</i> <i>Dorcatherium</i>
Miocene	None	<i>Dromomeryx</i> <i>Blastomeryx</i>	<i>Dorcatherium</i> <i>Dremotherium</i>	(No record)	<i>Dorcatherium</i> ⁶²
Oligocene	None	<i>Leptomeryx</i> ⁶⁰ etc.	<i>Prodremotherium</i> <i>Gelocus</i> etc.	None	<i>Prodremotherium</i> <i>Gelocus</i> etc.
Eocene	None	Primitive Artiodactyla		No record	

The antelopes, on the other hand, while also appearing fairly early in the European geologic record and abundant and well advanced in southwest and southern Asia as early as that record is revealed to our eyes, are imperfectly represented in North America—first appearing in the Pliocene and not widely varied even to-day, while they have not reached South America at all. They are to-day most abundant and varied in Africa. From these facts, I infer that their center of dispersal was well to the

⁶⁰ Family Hypertragulidæ, but *Leptomeryx* is structurally ancestral to American Cervidæ.

⁶¹ This group is referred generally to the Tragulidæ, but the common characters are persistent primitive features, and I regard it as a little altered survivor of the ancestors of the Cervidæ. Tragulidæ as here limited are a distinct phylum, primitive in many features but aberrant in others.

⁶² Family Tragulidæ as usually referred, but affinities are with *Hyæmoschus*, not with *Tragulus*; the group may fairly be regarded as ancestral to the Cervidæ, while the traguline group certainly is not.

A. Muskoxen (*Ovibovinae*)B. Sheep and goats (*Ovinae*)C. Other Antelopes (*Antelopinae* etc.)D. Cattle (*Bovinae*)FIG. 24. *Distribution of the Bovidae, existing (solid black) and extinct (shaded)*

The sheep and goats are regarded as the highest group; the muskoxen represent a specialised Arctic adaptation (*cf.* Eskimo among mankind). The cattle are a somewhat southerly type; their formerly wide northern distribution has been greatly restricted, and for the theory that they are of Oriental origin there does not appear to be any real evidence. The remaining Bovid subfamilies, usually grouped under the term "antelopes," are to a varying extent primitive and aberrant. The Holarctic groups are nearer to the sheep and goats and the more primitive groups are limited to the Ethiopian region and the East Indies.

west and south in Asia (*cf.* rhinoceroses). The sheep and goats are a comparatively recent development of the highest antelopes and must be assigned a center of dispersal somewhat more to the north.

The cattle are of comparatively recent appearance in Europe, as also in America. Judging from their present distribution, one would say that their center of dispersal was in southeastern Asia, the southward slopes of the Himalayas.

FIG. 25.—*Distribution of the Giraffes, existing (solid black) and extinct (shaded)*

On present evidence their dispersal center would appear to have been in south central Asia. But the affinities of the Tertiary Giraffidae to other contemporary ruminants need careful and judicial reconsideration.

The giraffes have approximately the same center of dispersal as the antelopes. This inference from their modern distribution conforms with the geological record. They appear suddenly in the upper Miocene of Europe, but an ancestral series is found in India as far back as the upper Oligocene.⁶²

⁶² See G. E. PILGRIM: *Rec. Geol. Sur. Ind.*, vol. XLIII, p. 301. 1913.

TABLE XII.—*Distribution of Bovidæ and Antilocapridæ*

	Neotropical	Nearctic	Palæarctic	Ethiopian	Oriental
Recent	None	<i>Ovis</i> <i>Oreamnus</i> <i>Bison</i> <i>Antilocapra</i>	Sheep and Goats!! Cattle Antelopes	Cattle Ante- lopes!!	Cattle!! Antelopes!
Pleistocene	None	<i>Bison</i> <i>Antilo- capra</i>	Sheep and Goats Cattle! Antelopes!	Cattle Antelopes	Cattle Antelopes
Pliocene	None	[<i>Meryco- dus</i>] ⁶⁴	Cattle Antelopes!!	(No record)	Cattle!! Ante- lopes!!
Miocene	None	[<i>Meryco- dus</i>] ⁶⁴	Antelopes!! (late Mio- cene)		Cattle!! Ante- lopes!!
Oligocene	None	None	[Ancestral Primitive Ruminants]	None	None

⁶⁴ *Merycodus* is a distant relative, combining characters of Bovidæ and Cervidæ.

TABLE XIII.—*Distribution of Giraffidæ*

	Nearctic	Palæarctic	Ethiopian	Oriental
Recent	None	None	<i>Giraffa</i> <i>Ocapia</i>	
Pleistocene	None	None		
Pliocene	? None	None (unless in China)	(No record)	<i>Sivatherium</i> <i>Hydaspithe-</i> <i>rium</i> <i>Giraffa</i> etc.
Miocene	? None	<i>Helladotherium</i> <i>Samotherium</i> etc.	(No record)	? <i>Giraffa</i> <i>Progiraffa</i> etc.
Oligocene	[<i>Syndyoceras</i> and <i>Proto-</i> <i>cceras</i> ⁶⁶	Ancestral Primitive Ruminants	None	<i>Progiraffa</i> (? ancestral to the Giraf- fidæ)

⁶⁶ Remote and archaic collateral relatives, family Protoceratidæ. It is by no means certain that *Dromomeryx* and other undescribed genera from the North American Miocene provisionally referred to the Cervidæ and Brachyodont Bovidæ are not related to the Giraffidæ; but on present evidence the dispersal center of the family appears to be India, and their range confined to Palæogæa.

Besides these surviving groups of ruminants, there are several groups which have not survived. The anthracotheres are one of the earliest of these specialized races; I have elsewhere⁶⁶ detailed the data upon which may be predicated a North Asiatic center of dispersal for this group. The living hippopotami show a modicum of resemblances to this type, which may mean that they are derived from some early members of it. Their present habitat is Ethiopian; but in the Pliocene and Pleistocene their range was far to the northward—even as far as England on one

FIG. 26.—*Distribution of the Anthracotheres and Hippopotami*

The Anthracotheres were a large and widely dispersed group in the Oligocene and Miocene, especially in the Old World, but found also in the Oligocene of North America. The Hippopotami appear to be specialized survivors from the same stock; they are confined to the Old World and their range has been greatly restricted since Pliocene and Pleistocene.

hand and northern India on the other. While the present distribution of the large hippopotamus is Central Africa, smaller and more primitive precursors have been stranded on the one side in West Africa, on the other (now extinct) in Madagascar and also found refuge in the Mediterranean islands until the Pleistocene. (The aquatic habits of the hippo-

⁶⁶ Bull. A. M. N. H., vol. xxvi, pp. 1-7. 1909.

potamus have enabled it to reach these island retreats more easily than terrestrial competitors.)

TABLE XIV.—*Distribution of Anthracotheres and Hippotami*

	Nearctic	Palæarctic	Ethiopian	Oriental	Malagasy
Recent	None	None	<i>Hippopotamus</i> <i>Chæropsis</i>	None	None
Pleistocene	None	<i>Hippopotamus</i> <i>Chæropsis</i> " (Cyprus)	<i>Hippopotamus</i>		<i>Hippopotamus</i> (dwarf species)
Pliocene	None	<i>Hippopotamus</i>	(No record)	<i>Hippopotamus</i> <i>Hexaprotodon</i> <i>Merycopotamus</i>	(No record)
Miocene	<i>Arretotherium</i>	<i>Brachyodus</i>	Anthracotheres	<i>Anthracotherium</i> <i>Hemimeryx</i> <i>Sivameryx</i> etc.	
Oligocene	<i>Anthracotherium</i> <i>Ancodus</i>	<i>Anthracotherium</i> <i>Ancodus</i> "Brachyodus"	<i>Ancodus</i>	<i>Merycop</i> <i>Hyoboops</i> "Brachyodus" <i>Anthracotherium</i>	(No record)
Eocene	None	<i>Ancodus</i>	(No record)		

The remaining groups of ruminants are not of especial interest in this discussion. The entelodonts are Holarctic; the oreodonts Nearctic; anoplotheres and cænotheres Palæarctic; there is no evidence that they originated elsewhere or that they reached any other zoölogical region. *Entelodon* (*sensu lato*) appears simultaneously in Europe and the United

" *H. minutus* is (vide Bate) congeneric with the Liberian species. The rules of priority call for the application of *Hyopotamus* Kaup to this genus, instead of *Chæropsis*.

States in the beginning of the Oligocene, without direct ancestry in either continent, and is regarded by Peterson⁶⁸ as probably from an Asiatic source.

FIG. 27.—*Phylogeny and distribution of the Artiodactyla*

Most of the families appear to have originated in the Nearctic or Palearctic region and spread thence outwardly to the more peripheral regions. The higher types are of more recent origin and are still dominant in the Holarctica.

PROBOSCIDEA

The later Tertiary and Quaternary history of the mastodons and elephants agrees with the various groups that we have been considering in indicating Asia as the center of distribution of the race. Elephants are now limited to the Ethiopian and Oriental regions, but in the Pleistocene their range was over the whole of Europe, Asia and North America, as well as Africa. The northern species, although of smaller size, are more progressive than the southern species in the specialization of the teeth, proportionate length of tusks, shortening of skull with concomitant elongation of trunk. The more primitive mastodons first appear in India in the Oligocene, in Europe in the lower Miocene, in North America in the middle Miocene. The intermediate stages leading to the mammoths and elephants are best shown in the Pliocene and Pleistocene of India; a less exact series may be found in North America. The mastodons reached South America in the Pleistocene; the mammoths and elephants never reached that continent. The earlier stages in the phylogeny of the Pro-

⁶⁸ O. A. PETERSON. *Mem. Carb. Mus.*, vol. iv, pp. 145-148. 1909.

boscidea have not, however, been found either in Europe or North America but have been recognized in the Oligocene of Egypt. From this fact, it has been generally concluded that the Proboscidea first evolved in the Ethiopian region. But it should be remembered that northern Egypt is not strictly within the Ethiopian region but belongs with all of northern Africa to the Mediterranean subregion of Holarctica. Owing to its proximity to the Ethiopian region, it contains Ethiopian elements in its modern fauna and may have contained more in the past. But it is not clear that the Oligocene Proboscidea must be numbered among these. There is no evidence that their center of dispersal was not Asiatic in early as in later Tertiary;⁶⁹ but it must have been too far to the south to admit of their reaching Europe or North America, until after their spread into northeast Africa. We must therefore conclude, apparently, that the dispersal center was transferred to the north and east during the course of the Tertiary—a quite exceptional feature, beside which the question of its original location, whether in southern Asia or in Africa, appears much less important.

TABLE XV.—*Distribution of the Proboscidea*

	Neotropical	Nearctic	Palæarctic	Ethiopian	Oriental
Recent	None	None	None	<i>Lorodon</i>	<i>Elephas</i>
Pleistocene	<i>Dibelodon</i>	<i>Elephas</i> <i>Mastodon</i>	<i>Elephas</i> <i>Mastodon</i>	<i>Elephas</i> ? <i>Trilophodon</i>	?
Pliocene	None	<i>Dibelodon</i>	<i>Elephas</i> <i>Mastodon</i> <i>Tetra-</i> <i>lophodon</i>	(No record)	<i>Stegodon</i>
Miocene	None	<i>Trilophodon</i>	<i>Trilophodon</i> <i>Dinoth-</i> <i>erium</i>	<i>Dinoth-</i> <i>erium</i>	<i>Tetralophodon</i> <i>Trilophodon</i> <i>Dinotherium</i>
Oligocene	None	None		<i>Palæomas-</i> <i>todon</i> <i>Mærithe-</i> <i>rium</i>	<i>Hemimasto-</i> <i>don</i> <i>Dinotherium</i> ? <i>Mærittherium</i>
Eocene	None	None	None	<i>Mærithe-</i> <i>rium</i>	(No record)

⁶⁹ Certainly the Proboscidea of the Oligocene Gaj fauna of India are far more advanced than the Egyptian Fayûm genera, if Pilgrim's correlation of the Gaj beds is correct. This, by our methods of interpretation, would indicate that India was much nearer than Egypt to the dispersal center.

SIRENIA

The most primitive sirenians are found in the late Eocene of Egypt. As these were apparently contemporary with more progressive types in the Middle and Upper Eocene and Oligocene of Europe, they indicate, if anything, that the Mediterranean shores held a less progressive fauna than the North Atlantic. The Oligocene and Miocene types are approximately ancestral to both the modern groups, manatees and dugongs. Apparently the manatees became characteristic of the North Atlantic, the dugongs of the Indian Ocean shores. The progressive cold of the later Tertiary and Pleistocene has driven the manatees out of the Arctic and northerly Atlantic shores and their northern limit is now Florida on the western, and the African coast on the eastern side. They have not been found fossil north of 40° N. lat. on the American coast,⁷⁰ for the excellent reason that there are practically no Tertiary littoral deposits north of that latitude.

The occurrence of *Manatus* in West Africa and in the West Indian and South American coasts is among the arguments used in support of a transatlantic bridge; but there is no evidence at all that the ancestors of *Manatus* did not inhabit the whole of the North Atlantic and Arctic basin during the Tertiary. It is certain that they did inhabit parts of the intervening European and American littoral, and the negative evidence elsewhere is obviously worthless, because there are no formations known in which they might be found.

CONDYLARTHRA AND SPECIALIZED SUCCESSORS

We may here consider the distribution of a number of extinct groups of Tertiary ungulates or semi-ungulates, whose rise and culmination took place at an earlier epoch and under different conditions from those which we have discussed. The Condylarthra are an extremely primitive group of hoofed mammals, fulfilling nearly the theoretical requirements for the common ancestral type of all placental ungulates. The earliest known artiodactyls and perissodactyls are, however, too much specialized to be immediately derived from the known Condylarthra. Condylarths first appear in the Paleocene of North America and Europe and in South America in the *Notostylops* fauna, here regarded as Eocene. In North America, they develop through the Taligrada into the Amblypoda, culmi-

⁷⁰ For distribution of manatees during Tertiary *vide* Hay, Bibl. Foss. Vert. N. A., U. S. G. S. Bull. 179, p. 583-4, 1902; of Old World Sirenians, Abel, 1904. Abh. Geol. Reichsanst., xix Bd., s. 214; 1906, Neues Jahrb. Bd. II, s. 50-60; 1912, Palaeontographica, lxx Bd., s. 292.

nating in the highly specialized Dinocerata. In South America, they apparently develop during the Tertiary in absence of Artiodactyla and Perissodactyla into a great variety of hoofed mammals, the Toxodontia and Typotheria, Litopterna, Astrapotheria, Pyrotheria. The Arsinoitheria of the Oligocene of Africa, perhaps also the Hyracoidea and Proboscidea, may also be regarded as evolved from primitive Condylarthra, in absence of the higher ungulates of the Asiatic center of dispersal. We have therefore direct or inferential evidence that at the beginning of the Eocene the Condylarthra inhabited the Palearctic, Nearctic, Neotropical and Ethiopian regions. There is no reason to suppose that they were

FIG. 28.—*Relationship of the Condylarthra to the Notoungulate and Subungulate groups of hoofed mammals*

In indicating the distribution, Egypt, Syria etc. have been included with Ethiopia, as the essential facts in this case could thus best be represented. "Eumotheria" are the common ancestral stock (hypothetical) of the Creodonta-Carnivora-Condylarthra-Amblypoda group.

absent from the Oriental region, but they evidently did not reach Australia or Madagascar.

The worldwide dispersal of the condylarths at the opening of the Tertiary (partly hypothetical and exclusive of Australasia and Madagascar) may be regarded as due to the epoch of elevation and disturbance which closed the Cretaceous. The subsequent development of peculiar and highly specialized ungulates during the Eocene in the several great continents is attributable partly to the isolation of these continents during that period due to submergence of the low lying connecting regions,

partly to the prevalence of more uniform climatic conditions all over the world and the consequent lack of environmental pressure tending to force a change in habitat. Towards the end of the Eocene began a period of progressively intensified elevation and disturbance, with refrigeration of climate beginning at the poles; this culminated in the Glacial epoch. The northern fauna successively invaded the tropical and southern continents and swept before it nearly all their autochthonic faunæ.

In Africa, we see this invasion in progress in the Oligocene; the anthracotheres, forerunners of the great ruminant invasion have already appeared; to these may yet have to be added *Palæomastodon* as a forerunner of proboscidean invaders (although on the present record the Proboscidea may appear an autochthonic group); while the hyracoids, with *Mærittherium*, *Arsinoitherium*, *Barytherium* and some less known types are apparently autochthonic since Paleocene. Unfortunately, our view stops here; we know little of the progress of this invasion until the late Pliocene, when these invaders had themselves disappeared before a succession of later invasions or become modified into new types.

In South America, the isolation lasted much longer, and owing to the great southward extension of the continent, a highly progressive independent center of dispersal was set up in Argentina. Whatever criticisms may be made of the phyletic theories of Dr. Ameghino, so far as they affect the evolution of the mammalian races of the northern world, I think that there can be no question that he has brought out a remarkably complete series of phyla in the autochthonic races of South America. The closeness of these series, and the large amount of progressive evolution which they involve, on lines analogous to those of the northern mammals, are fair indices that the controlling forces were similar and that the southern end of the continent was the chief center of dispersal. The various types of structure which were developed in northern mammals during the Tertiary, in adaptation to the progressive change of environment, are almost all paralleled, occasionally exceeded in degree by these southern races; but they are very generally seen in different combinations, as Professor Gaudry has so clearly shown.⁷¹

Had the Condylarthra reached Australia, we should expect to find there a group of placental ungulate orders peculiar to the region, like those of Tertiary South America, persisting to the present day. But we find, instead, that the marsupials evolved into the herbivorous fauna. In Madagascar the lemurs may be regarded as filling the place which

⁷¹ ALBERT GAUDRY: *Annales de Paléont.*, t. III, pp. 41-60. 1908.

primitive ungulates would have taken, if they had reached the island; but the case is not so clear.

EDENTATA

The edentate orders afford among the ungulates a broad parallel in their distribution and history to the Condylarthra and their successors among the ungulates. Their extinction has been somewhat less complete; a few highly specialized survivors remain in the Neotropical, Ethiopian and Oriental regions.

////// *Xenarthra* \\\\\\\ *Pholidota* ||||| *Tubulidentata*

FIG. 29.—Distribution of the Edentate orders

The New World edentates or *Xenarthra* may have originated in Cretaceous North America, but their Tertiary dispersal centers were South American, apparently in or near to Patagonia. The dispersal centers of the *Pholidota* and *Tubulidentata* would appear to have been Palearctic, but very little is known of their fossil record.

The super-order Edentata is an artificial assemblage including the three surviving orders *Xenarthra*, *Pholidota* and *Tubulidentata* and the extinct order *Tæniodonta* (= *Ganodonta*). The *Tæniodonta* of the Eocene of North America may perhaps be regarded in a broad way as representing the primary type of the *Xenarthra*, but even this is doubtful.

They are far more primitive and nearer to the generalized eutherian type; but they show certain unique Xenarthran peculiarities in foot-construction and in the pelvis, and the dentition in the two known phyla progressively evolves on lines leading towards, although not into, the

PHYLOGENY OF THE EDENTATES

FIG. 30.—*Distribution and phylogeny of Xenarthra and Tardigrada*

The aberrant North American groups appear to be relicts indicating a northern origin of the Xenarthra, but the evidence is not conclusive.

specialized edentate types. The Tæniodonta range from Paleocene to Upper Eocene in North America and are doubtfully recorded in the early Eocene of Europe. They may be hypothetically regarded as a Cretaceous-Eocene ancestral group in the northern world, from whose early members budded off the ancestral Xenarthra in the Nearctic, possibly also the Pholidota and Tubulidentata in the Palæarctic, the whole group being driven southward at the beginning of the Tertiary, except for a few lingering remnants, rare and little known. Of these lingerers, we may instance in the (Bridger) mid-Eocene of Wyoming *Metacheiromys*, whose affinities are distinctly armadilloid and an unnamed but more primitive genus in the Lower Eocene of Wyoming approximately ancestral to it; "*Lutra*" *franconica* of the Oligocene of Germany, shown by Schlosser to be related to the Aardvark, *Palæomanis* and *Orycteropus* of the Miocene of Samos, and more doubtfully *Palæorycteropus* and *Necrodasypus* (in part) of the Oligocene of France.

Whether the rare ground-sloth remains from the (?) Middle Miocene⁷² and Lower Pliocene of the western United States are to be regarded as surviving Northern edentates or as immigrants from the south is not certain, but the latter explanation is more probable.

The Old World edentate groups, although still surviving in Ethiopia (*Manis*, *Orycteropus*) and the East Indies (*Manis*), are not known to have undergone any considerable expansion during the isolation-period of the early Tertiary.⁷³ The Xenarthra, on the other hand, are first represented in the early Tertiary of South America by armadilloid forms and they blossomed out in the isolated continental conditions that prevailed during the Tertiary in that continent into a wide range and diversity of type, just as the Condylarthra appear to have done under the same conditions there and the marsupials in Australia. Of the five principal groups—tree-sloths, ground-sloths, anteaters, armadillos and glyptodonts—only the second, fourth and fifth are known as fossils, and only the first, third and fourth have survived. The fossil groups reached their maximum of size and specialization in the Pleistocene, and reinvaded North America in the Pliocene and Pleistocene (possibly earlier,

⁷² There is some question as to the true horizon of the ground-sloth claw found by Sinclair in the Mascall formation (Middle Miocene) of Oregon. The specimen may have washed down from the overlying Rattlesnake Beds, Lower Pliocene [oral communication from J. C. Merriam].

⁷³ But this may be due only to the imperfection of the geologic record. We know nothing of the early Tertiary faunæ of the Ethiopian and Oriental regions, save for the Oligocene of Egypt. The Eocene faunæ of South Africa, India and the East Indies may have included a considerable expansion of pholidate or tubulidentate mammals, corresponding to the xenarthral expansion of the New World, but earlier extinguished because of the earlier invasion of those regions from the north.

vide supra), but only the armadillos have maintained any foothold in the northern world until modern times and these only in the southwest corner of the Sonoran region. The anteaters and tree-sloths might be expected to have originated in Patagonia and to have been driven northward to tropical South America in accord with the theory of climate and evolution here advocated. The geological record, however, has failed to show any certain evidence of this, and, as the Patagonian record is a comparatively full one, this fact should be counted as evidence that climatic change is not the only causal factor of evolution. We must suppose, if the record be adequate, that these groups originated and evolved in tropical South America. The armadillos are an extremely persistent group, and the record gives no really convincing evidence of a Patagonian dispersal center, although it might be so interpreted.

Glyptodonts and ground-sloths appear in the Pliocene and Pleistocene of North America. The Pleistocene genera except *Megalonyx* are closely allied to the genera of the Pampean formation, in part identical therewith (*Brachystracion*, ? *Glyptodon*, *Chlamydotherrum*, *Megatherium*, *Megalonyx*, *Nothrotherium*, *Mylodon*). These, or allied genera equivalent in specialization, inhabited South America from Ecuador to Patagonia in the late Pliocene and Pleistocene. The only genera found in the Pliocene of North America are *Megalonyx* and *Glyptotherium*, decidedly more primitive and are best interpreted as earlier forerunners of the main invasion which appeared at the beginning of the Pleistocene. *Mylodon* has been recorded from the Blanco beds of Texas, but this is an error.

MARSUPIALIA

Marsupials are at present almost limited to the Australian and Australo-malayan region, where, in the absence of placental mammals, they have diversified into a wide variety of size, habits and adaptation, paralleling the adaptive radiation of the higher mammals in the northern continents. A single unspecialized group, the opossums, representing quite nearly the primitive type from which all marsupials are derivable, survives in the Neotropical region, one or two of its species ranging northward into the Sonoran subregion of Holarctica. Another primitive survivor in the Neotropical region is the rare little *Cænolestes*, formerly regarded as a primitive member of the diprotodont marsupials, but now considered to be of polyprotodont affinities, its diprotodont resemblances being due to parallelism.

What we know of the paleontology of the order is in complete accord with the theory of their being primarily of northern origin, their dispersal preceding that of the early placentals.

The fragmentary and little known mammals from the Mesozoic formations of Europe and North America were in large part marsupials, so far as we can judge from what is known of them.

The most distinctive group among them were Multituberculata or Allotheria. Gidley¹⁴ has recently (1909) brought forward strong evidence for the view that these animals were an archaic, early specialized branch of the marsupials paralleling the later diprotodonts.¹⁵ They occur (doubtfully) in the Rhætic of Germany, certainly in the Upper

////// *Opossums* === *Cænolestes* \\\\\\ *Dasyures; Diprotodontia*

FIG. 31.—*Distribution of Marsupials*

This is probably to be regarded as due to a very ancient dispersal from the north, followed by differentiation and dispersal during the Tertiary of specialized adaptations parallel in the Neotropical (Borhyaenids and Cænolestids) and Australian regions (Thylacine-Dasyures and Diprotodontia). The Phalangers of the Austromalayan islands are regarded as marginal types from an Australian dispersal center.

¹⁴ J. W. GIDLEY: Proc. U. S. Nat. Mus., vol. xxxvi, pp. 611-626. 1909.

¹⁵ Recent discoveries, made since these lines were written, indicate that the relationship was not as close as had appeared. Dr. Broom has even maintained that these animals were nearer to monotremes than to marsupials, but in my judgment he has failed to adduce any really valid evidence for this view. But while they are in the Metatherian stage of evolution I do not think they can be included in the order Marsupialia on the data now available. See forthcoming article by Walter Granger in Bulletin Am. Mus. Nat. Hist.

Jurassic and Lower Cretaceous of England (*Plagiaulax*⁷⁶) and Wyoming (*Ctenacodon*). They again appear in the uppermost Cretaceous and Paleocene of North America (Lance formation of Wyoming, Fort Union of Montana, Puerco and Torrejon of New Mexico) and Europe (Cernaysian) in the genera *Ptilodus*, *Neoplagiaulax*, *Polymastodon* and *Meniscoëssus*. They are questionably recorded in the Eocene *Notostylops* beds of Patagonia, in the genera *Propolymastodon*, *Polydolops* etc. (which more probably belong to the same group as *Cænolestes*). They are not known elsewhere except for part of a jaw from the middle Cretaceous (Belly River) of Canada and a jaw (*Karroomys*) from the Jurassic (Karoo beds) of South Africa. The front half of a skull long ago found in the Karroo beds and described as *Tritylodon* is probably to be referred to this group, although its mammalian nature has been questioned.⁷⁷

In addition to the Multituberculata, there are in the Jurassic and basal Cretaceous of England and Wyoming a number of mammals with simpler and more numerous teeth whose affinities are very uncertain. Whether they are ancestral to marsupials, to placentals, to both or to neither is, in the writer's opinion, an unsettled question. Its definite solution must probably await the discovery of more complete material.

In the uppermost Cretaceous (Lance formation) of Wyoming are found in addition to teeth and jaw fragments of Multituberculata, a variety of tritubercular teeth, some associated with fragments of the jaw. These appear to be more definitely referable to the polyprotodont marsupials; some of them may be quite near to the opossum. I have seen no evidence among them of placental mammals, although most of them are too fragmentary to exclude the possibility of the presence of Eutheria.

The Paleocene fauna of New Mexico, Montana and France contains numerous placentals and a few Multituberculata, but no polyprotodont or true diprodont marsupials have yet been positively recognized in it. It is evidently not derived (except for certain of the Multituberculata) from the fauna of the Lance formation. Yet it is almost, perhaps quite, contemporaneous with it and must be supposed to represent a distinct facies of the fauna, differing in habitat from that of the Lance formation (the Fort Union is partly intermediate). Polyprotodont marsupials certainly persisted in North America and Europe, for we find the remains of species nearly related to the existing opossums in the Lower and Middle

⁷⁶ *Bolodon* is a synonym of *Plagiaulax*, vide Gidley.

⁷⁷ Broom has recently made a careful restudy of the affinities of *Tritylodon*, and concludes that it is a mammal, but not closely related to the marsupials, and represents an archaic specialization with many primitive characters inherited from the cynodont reptiles. R. Broom: Trans. S. Af. Phil. Soc., vol. xvi, pp. 73-77. 1905. Proc. Zool. Soc. London, 1910, pp. 760-768. 1910. Bull. Am. Mus. Nat. Hist., vol. xxxiii, pp. 115-134. 1914.

Eocene of Wyoming, in the Oligocene of Colorado and in the Upper Eocene to lower Miocene of France and Germany. They are not known from any later formation in any of the northern continents.

In the Southern continents, they assumed a much more important position. In South America, in the absence of placental carnivora, the polyprotodont marsupials developed into a number of large and small predaceous mammals (Borhyænidæ), so closely paralleling some of the predaceous marsupials of Australia that they have been referred to the same family (Thylacinidæ). Pseudo-diprotodont marsupials were also fairly common, taking the place in the fauna held by Insectivora in the North, this group of placentals (except for a single type) not having reached South America. The marsupials of South America did not develop into groups taking the place of northern ungulates, rodents or primates, since primitive placentals of these groups (Condylarthra, ? Hystricomorpha, ? Lemuroidea) had penetrated into South America before it was separated from the Northern world, and there developed along lines sub-parallel to the development of the higher placental groups in the North, but distinct and less progressive.

In Australia, the marsupials assumed a still more important position, as the only mammals of that continent. The placental mammals of the northern Tertiary did not reach Australia, except for a few strays—bats and mice and the dingo—which were too few in numbers and of too recent introduction to affect seriously the course of mammalian evolution on that continent. In the absence of placentals, the marsupials developed into a wide variety in size, form and habits of life, partially paralleling the higher mammals.

The near resemblance between the modern Australian *Thylacinus* and the Borhyænidæ of Tertiary South America has been used as an argument for an Antarctic connection between the two. Such a hypothesis will not bear close examination. The resemblance is not closer than between parallel adaptations in distinct families of true Carnivora, whose genealogy has been more or less completely traced back through independent lines of descent from unspecialized common ancestors. It is not closer, for instance, than that between the Oligocene Felidæ and the modern *Cryptoprocta* of Madagascar, whose common descent from an unspecialized placental carnivore (Viverrid or Miacid), analogous to the marsupial didelphyids, is generally admitted. The common characters distinguishing thylacinids and borhyænids from the didelphyids are, without exception, such as would naturally be assumed independently in adaptation to predaceous terrestrial life and have been so assumed in numerous independent parallel adaptations of the same sort among

placental Carnivora. On the other hand, *Thylacinus* has retained certain didelphyid characters which are already lost by the most primitive of the Borhyænidae (palatal vacuities, posterior position of the orbits,⁷⁸ an external lachrymal duct, double perforation of the basisphenoid), while in other features (brain development, cursorial specialization, etc.) it is more progressive. The Borhyænidae are more progressive in the reduction of the last molar, in the differentiation of enamel from dentine, less so in the cursorial adaptation of the limbs and feet.

Descent from a common ancestral type is undoubtedly shown, but some at least of the above differences point back to Didelphyidae as this common type. The characters which Sinclair uses to separate the thylacines are the reduced number of incisors, the carnassial specialization of the molars and especially the loss of the metaconid. Every one of these features, besides numerous other common characters which he does not specify, may be paralleled in two or more distinct lines of Carnivora whose common ancestors are not more predaceously specialized than *Didelphys*. The loss of the metaconid occurs in *Cyon*, *Ischyrocyon*, *Simocyon* and *Enhydrocyon* among the Canidae, in all the post-Oligocene Felidae, in *Gulo*, *Megalictis*, *Mustela*, etc., among the Mustelidae, in the later Hyænidae, in *Hyænodon* and *Pterodon* among the Hyænodontidae, in *Patriofelis* among the Oxyænidae, in all the later Mesonychidae. Each one of these genera is independently descended from genera in which the metaconid is well developed. In every case, it is simply a stage in predaceous adaptation of the molars, nor can it be assigned any other significance in the marsupial carnivores. There is, in short, no evidence for assuming a closer affinity between thylacines and borhyæuids than common descent from didelphyid ancestors, and there is strong evidence against such an assumption. But if this be true, these animals afford no evidence for Antarctic connections between the southern continents; for we have seen that Didelphyid marsupials were certainly present in the Mesozoic and early Tertiary of Holarctica and of South America, and we have no reason to believe that they would have had greater difficulty in reaching Australia in the Mesozoic or early Tertiary than the murine rodents found at a later date.

The supposed presence of Diprotodont marsupials in the South American Tertiary and in modern Australia has also been used in support of Antarctic connections between the two continents. The recent morphologic studies of Dederer⁷⁹ and Broom⁸⁰ have shown that *Cænolestes*

⁷⁸ Interpreted by Sinclair as a progressive character in *Thylacinus*, but certainly the reverse in analogous placental adaptations.

⁷⁹ PAULINE H. DEDERER: Amer. Nat., vol. xliii, p. 614. 1909.

⁸⁰ R. BROOM: Proc. Linn. Soc. N. S. W., vol. xxxvi, p. 315. 1911.

is not a true diprotodont, but in fact belongs to the polyprotodont division of the Marsupialia, and with this genus must be associated all of the Epanorthids and probably all of the so-called Paucituberculata of the South American Tertiaries. If then the Diprotodonta, so dominant and so widely varied in Australia, were wholly absent from South America, while parallel adaptations were developed there from the Polyprotodonta, the distribution of these marsupials affords a valid argument against instead of for any Antarctic connection during the Tertiary.

In view of the great amount of adaptive divergence seen in the various Pleistocene and modern genera of Australian Diprotodonta, the origin of the suborder in Australasia or its earliest invasion of that zoölogical region, must be dated far back in the Tertiary. On our present evidence it may well be regarded as wholly autochthonic, derived from early Tertiary or possibly from late Mesozoic polyprotodonts. Nevertheless, in view of the defectiveness of the Mesozoic record, where we should chiefly expect to find this group, if anywhere in the North, and the presumable rarity of Tertiary survivors, there is nothing unlikely in the view that they originated primarily in the North like their polyprotodont and allotherian relatives and were driven southward with the former group and somewhat more thoroughly extinguished in the north, while in Australia they blossomed out into a great adaptive expansion paralleling the absent ungulate mammals.

It is probable that the opossums survived in North America throughout the Tertiary, although there is no clear record of them in our Miocene and Pliocene.⁸¹ But we know only a small part of our Pliocene fauna as yet, and the Miocene, although better known, represents chiefly the animals of the open plains, the forest fauna being very incompletely represented. On the other hand, it seems probable that the apparent disappearance of marsupials from Western Europe after the Lower Miocene was real, and it is probable that they had disappeared even earlier from Asia. They have not been found in the later Tertiaries of India or China, so that they must have been rare if not absent at that time. The Eocene Tertiary of Asia, where they might be expected to be common, is altogether unknown.⁸²

⁸¹ A very badly preserved skull from the Colorado Miocene and a jaw fragment from the South Dakota Miocene in the American Museum collections are perhaps marsupials; but I have never been able to see in either specimen satisfactory proof that they were so, and have consequently never recorded them.

⁸² The earliest Asiatic Tertiary fauna is that of the Bugti beds of India, lower Burdigalian or upper Aquitanian according to Pilgrim, *Rec. Geol. Sur. India*, vol. xliii, pt. 4, pp. 264-326. It is therefore either late Oligocene or early Miocene.

TABLE XVI.—*Distribution of Polyprotodont Marsupials*

	Neotropical	Nearctic	Palæarctic	Ethiopian	Oriental	Australian
Recent	Didelphyidæ <i>Cænolestes</i>	<i>Didelphys</i>	None	None	None ⁸³	Thylacinidæ Dasyuridæ
Pleistocene	Didelphyidæ	<i>Didelphys</i>	None	None	None	Thylacinidæ Dasyuridæ
Pliocene	Borhyænidæ ⁸³ Didelphyidæ Epanorthidæ	None known	None	(Record in- adequate)	None	(No Mesozoic or Tertiary record)
Miocene	Borhyænidæ Didelphyidæ Epanorthidæ	? ⁸⁴	None after lower Mi- cene	(No record)	None	
Oligocene	Borhyænidæ Didelphyidæ	<i>Peratherium</i>	<i>Peratherium</i>	None	(No Mesozoic or Early Tertiary record)	
Eocene	<i>Polydolops</i> , etc Borhyænidæ Didelphyidæ <i>Caroloame- ghinia</i>	<i>Peratherium</i>	<i>Peratherium</i>	(No Mesozoic or Eocene record)		
Cretaceous	<i>Proteodidel- phys</i> ⁸⁴	Cimolestidæ <i>Thlæodon</i>	(No record)			
Comanche		(No record)				
Jurassic		Triconodontidæ				

⁸³ Fragmentary remains, referred to Hyænodontidæ by Dr. Ameghino.⁸⁴ Jurassic, fide Ameghino.⁸⁵ Doubtful fragments of jaws which may be Didelphyid.⁸⁶ Except on borders of Australian region.

TABLE XVII.—*Distribution of Diprotodont and Pseudodiprotodont Marsupials and Allotheria (Multituberculata)*

	Paucituberculata	Allotheria			Diprotodontia vera
	Neotropical	Nearctic	Palæarctic	Ethiopian	Australian
Recent	<i>Cænolestes</i> ⁸⁷	None	None	None	Macropodidæ Phaseolomyidæ etc.
Pleistocene		None	None		Diprotodontidæ Macropodidæ Thylacoleonidæ etc.
Pliocene	<i>Epanorthidæ</i> ⁸⁸	None	None		
Miocene	<i>Epanorthidæ</i> ⁸⁸	None	None		
Oligocene	<i>Epanorthidæ</i> ⁸⁸	None	None	None	<i>Wynyardia</i> ⁸⁹
Eocene	<i>Polydolops</i> etc. ⁸⁸	?	None		
Paleocene		<i>Ptilodus</i> <i>Polymastodon</i> etc.	<i>Neoplagiulax</i>		
Cretaceous		<i>Ptilodus</i> <i>Meniscæsus</i> etc.			
Comanche					
Jurassic		<i>Ctenacodon</i> etc.	<i>Plagiulax</i> etc.	<i>Tritylodon</i>	
Triassic			<i>Microlestes</i>	<i>Karroomys</i>	

⁸⁷ This genus is a pseudo-diprotodont, as its real affinities are with Polyprotodontia, as shown by Dederer and Broom, l. c.

⁸⁸ Affinities probably with *Cænolestes*.

⁸⁹ Combines Polyprotodont and Diprotodont characters.

MONOTREMATA

The monotremes are the lowest group of mammals, far removed structurally from any others. Their connection with the main stock must date back to the end of the Paleozoic era. Nothing is known of their evolutionary history. The Multituberculata of the Mesozoic and Basal Eocene are regarded by Broom as ancestral to them, but this view is not supported by additional evidence since obtained. *Xenotherium*⁹⁰ of the North American Oligocene, referred by its describer to the monotremes, is an Insectivore related to the Chrysochloridæ; *Scotæops*⁹¹ of the South American Tertiary is an Armadillo,⁹² and other genera referred by Ameghino to the Monotremes probably also pertain to other groups. We find them to-day limited to the Australian region, and surviving even there only by virtue of unusual specializations of habit; *Echidna* protected by its coat of spines, *Ornithorhynchus* by its amphibious habitat, both genera burrowing and nocturnal. Presumably, these genera represent the last relic of the early Mesozoic dispersal movements of the Mammalia.

SUMMARY OF THE EVIDENCE FROM DISPERSAL OF LAND MAMMALS

The foregoing review of the several groups of land mammals shows that the more recently evolved and dominant races of Mammalia are to-day mainly Holarctic, and many of them have not yet reached the more peripheral regions; that the ancestry of all these dominant races has been found in the Holarctic Tertiary formations, sometimes in Europe, sometimes North America, more generally a series in each country of equivalent approximately ancestral stages. Where the geological record is adequate, these races are shown to be newcomers in the peripheral continents which they have invaded, and any ancestral series is absent. Their representatives in the peripheral continents are to a varying degree primitive and allied to earlier stages in the evolution of the race as represented in the Tertiary record of Holarctica, but they have specialized more or less along parallel or divergent lines from the direct line of descent of the northern representatives.

When the parallel series in Europe and North America are sufficiently complete they are seen to be not parallel phyla of independent local evolution, but periodically recruited by more progressive new stages, appar-

⁹⁰ EARL DOUGLASS, 1905. (The name is preoccupied by *Xenotherium* Ameghino, 1904, a genus of typotheres.)

⁹¹ FL. AMEGHINO, 1887.

⁹² W. B. SCOTT: Rep. Prin. Exp. Patag., vol. 5, p. 12. 1903.

ently from a common center of dispersal. The relations are like those of one side and the other of a branching tree whose trunk region is unknown to us.

The more ancient and primitive groups of the Mammalia have mostly disappeared, or are in process of disappearance, from Holarctica. In the peripheral continents, they have undergone in many cases a notable local adaptive radiation and expansion, extensive in proportion to the isolation of these continents from the northern realm, more complete during the early and middle Tertiary than now. When the reunion to Holarctica permitted the northern fauna to invade the peripheral continents, these autochthonous groups were in general unable to maintain themselves against the competition of the more progressive northern races, and have either wholly disappeared or left a few scattered survivors, mostly aberrant specializations which did not come directly into competition with the invading races. The survival of the major part of the marsupial radiation in Australia is attributable to its continued isolation. The apparent fact that Neotropical races of Edentata were able to invade North America during the Pliocene and Pleistocene may be ascribed to two factors:

1) No Nearctic groups of closely analogous specialization existed at that time.

2) Owing to the far southerly extension of South America, the evolution of mammals in that region was, so far as controlled by climatic change, more progressive and more nearly equivalent to the Holarctic evolution than in Australia or Africa. Its products therefore were better able to maintain themselves against their northern competitors.

If we regard the Proboscidea as of Ethiopian origin, we must suppose that they too constitute an exception to the general rule that the races evolved in the peripheral regions have been unable to invade Holarctica. But the recent discoveries of Pilgrim and Cooper in the Oligocene of India tend strongly to show that the Proboscidea were from the first, as they certainly were in the later Tertiary, a group of Asiatic, not African, dispersal.

The dominant influence of climate in controlling the range of modern mammals has been emphasized by C. H. Merriam. The mammals adapted to north temperate or even boreal climate are the most specialized and last evolved members of their respective races. The most primitive survivors of northern races, and surviving members of races formerly abundant in the north, are met with chiefly in tropical regions. Similar relations are seen in the faunæ of the antarctic as compared with the southern tropical regions, although less obvious. This is especially seen in South

America. It is displayed there quite as clearly in races, such as the cricetine rodents, cervidæ, etc., which are admittedly of Northern origin, as it is in any autochthonous groups. Hence, it cannot be attributed to a general Antarctic dispersal center, but must be explained as a parallel evolution under similar climatic stimulus.

The general distribution of Mammalia on these lines is almost universally accepted; but many writers have pointed out certain supposed exceptions and found it necessary to account for them by various hypothetical continental bridges. A careful consideration of these supposed exceptions shows that, if due allowance be made for parallelism and for the imperfection of the record, each one can be more satisfactorily interpreted in accordance with the general law. And the acceptance of any such continental bridges would entail migrations of other groups which assuredly have not occurred. The hystricomorph rodents of South America afford a single exceptional instance, in which over-sea transportation from Africa appears to be the only reasonable interpretation of the evidence at hand.

I place much greater weight on the evidence from mammalian distribution than on that of any other terrestrial group for several reasons, as follows:

- 1) Their past history, the time, place and method of evolution of the various races, is better known than in any other group of land animals or plants.

- 2) The complexity of structure in the hard parts which are preserved as fossils is greater, affording a larger amount of evidence by which we may distinguish parallel or analogous races and determine the closeness of their real affinities. As Stehlin²⁸ has recently observed, a single tooth of a mammal affords as much structural evidence whereby to determine its relationships as the entire skeleton of most invertebrates. Where our evidence is thus limited (to a single tooth, for example), we may, and frequently do, find difficulty in deciding the exact affinities of a fossil mammal. But where we have the skull or the skeleton or even the entire dentition, the results are correspondingly sure and precise as the data are more extensive.

- 3) Owing to their nearness to ourselves, their large size and other causes, we are better able to understand their adaptation and observe and appreciate the factors which may affect their evolution and migration.

In dealing with the evidence furnished by the lower vertebrates and invertebrates, we are hampered by the wider limits of time within which the migration may have taken place, by the relative simplicity of the structure of the hard parts, which makes it less easy to distinguish paral-

²⁸ "Über die Säugethiere der Schweizerische Bohnerzformation." *Verh. Schw. Naturf. Gesell.*, 93 Jahresvers. 1910, Basel. P. 11 of separate.

lelism from immediate affinity,⁹⁴ by the relative scarcity of fossils as compared with living species (among land animals), and by our less certain knowledge of the causes which may control their evolution, their means of migration, and their true evolutionary history and affinities.

INTERPRETATION OF NEGATIVE EVIDENCE IN FOSSIL MAMMAL FAUNÆ

In considering a Tertiary mammal fauna, we must keep in mind the facts that there may be large facies of it that are represented imperfectly, if at all, in our records, and that there may be important parts of it which have left little or no record, owing to their habitat, small size or other circumstances. We may, with some reserve, conclude that the entire absence from the record of a group which is abundant in other faunæ indicates its real absence from the fauna. But we are not justified in so concluding in the case of rare or inconspicuous races. It is fair to assume that the absence of Perissodactyla from the Oligocene fauna of Egypt or the Miocene fauna of Patagonia was real, and not a matter of defective record. The same assumption would be unjustified in the case of didelphid marsupials and dilambdodont Insectivora respectively. But the most conclusive evidence of the absence of a certain group from a given fauna is that while it is not found fossil, another group is found to have become adapted on parallel lines, taking its place in the fauna. The absence of Perissodactyla and Artiodactyla from the Miocene of South America is confirmed by our finding Litopterna, Toxodontia and Astrapotheria, which parallel in adaptation the horses, rhinoceroses, tapirs, camels, etc., of the North; the absence of Carnivora by the parallel adaptation of marsupials to take their place. The evolution of lemuroid primates in Madagascar into large quadrupedal forms apparently paralleling certain groups of Ungulates,⁹⁵ affords some evidence that the Tertiary hoofed mammals were unable to invade Madagascar.

The absence of fissiped Carnivora from the recorded Oligocene fauna of Egypt would not be conclusive in itself; but, coupled with the exceptional variety and abundance of the more archaic creodonts of the family

⁹⁴ It may be noted in illustration of this point that a natural cast of the entire carcass of a mammal would afford far less secure information as to its real affinities than would a fossil skull, and less even than a lower jaw with reasonably perfect teeth. The parallel adaptations so frequently recognized among mammals lead to superficial resemblance of distantly related types whose true affinities are readily recognized by the internal structure. If, as among most invertebrates, we had only an external skeleton to guide us, the real affinities would not be so securely recognized.

⁹⁵ The skull and the short limbs of *Megaladapis* are very suggestive of such types as *Promerycochirus*. The feet do not, however, indicate a terrestrial habitat, nor are the teeth efficient in grinding. The resemblance in teeth and skull of *Archæolemur* to the Anthropoidea is very marked.

Hyænodontidæ, it is very strong evidence that fissiped Carnivora had not yet invaded the Ethiopian region, at least in any considerable numbers.

DISPERSAL OF REPTILIA

The essential adaptive feature which distinguishes mammals and birds from the reptiles out of which they arose lies in the non-conducting covering to the skin,—of hair or fur among mammals, of feathers among birds. The assumption of this covering enabled the body to be kept at a uniformly high temperature, thus favoring the maximum of bodily activity, and making it practicable to develop the circulation and the entire organization to a much higher standard. It also made these classes of animals independent of the temperature of their environment. It enabled them to withstand cold or variable climate and to take full advantage of the conditions of the colder regions, which appear to favor a higher development than can be attained in moist tropical countries.

The initial development of mammals and birds took place, so far as we are able to judge, during the great arid period of the Permian-Triassic. They appear to have been derived from unknown groups allied respectively to the theromorphous reptiles and to the ornithischian dinosaurs. We know almost nothing of their Mesozoic evolution, because the upland epicontinental formations of the Mesozoic, in which this record should be chiefly preserved, have been totally swept away, or if any remnants remain, they have not been recognized and sufficiently explored to recover it. The formations of the swamps and coastal marshes, river-deltas, littoral regions and shallow seas of the Mesozoic are extensively preserved and their inhabitants well known to us. But of the upland fauna, we get only an occasional glimpse in such deposits as those of Solenhofen, where a few remnants of the fauna of the adjoining uplands have been preserved in great perfection. We have, indeed, indirect evidence as to the nature of the upland fauna of the Mesozoic, for the successive groups of swamp dinosaurs, the marine birds and pterodactyls of the later Mesozoic and the abundant and varied mammalian fauna which appears at the beginning of the Tertiary are not derivable, any of them, from their predecessors in the swamp or marine faunæ, but must be traced back to ancestors distinctly adapted to dry-land life, which reinvaded the coast-swamp, littoral or marine provinces. This will appear more in detail in the discussion of the several orders. The point here to be emphasized is that the dry-land vertebrate fauna has been throughout the dominant facies and has repeatedly reinvaded the swamp and sea-coast provinces, the higher activity and better organization acquired on land giving its

members, when readapted to the marsh or littoral conditions, an advantage which enabled them to supersede the autochthonous dwellers in those conditions. *Per contra*, there have not been a succession of invasions of the dry land by the vertebrate inhabitants of swamp and sea-coast. Once established on dry land, the primary groups of dry-land reptiles held their own and evolved and expanded into higher types and greater variety, but they were not recruited, so far as the evidence shows, by new invasions from the swamp and aquatic fauna.

DINOSAURIA

The dinosaurs appear to be primarily a dry-land adaptation (properly speaking, two distinct but parallel adaptations) of the primitive reptiles.⁹⁶ Their most obvious adaptive characters lie in the long limbs and swift-running gait and the general parallelism to the ratite birds. As such, the conditions of life would tend to greater activity and higher development and enable them, when they reinvaded the swamps during the epochs of great swamp-extension, to reach greater size and dominance. It is these readaptions that are chiefly known to us and are apt to give the idea that the dinosaurs were distinguished by gigantic size and massive proportions. In fact, these are no more typical of the order as such than the whale, hippopotamus and elephant are fairly typical of the mammals as such. There must have been multitudes of small dinosaurs, mostly inhabiting the upland, a smaller number living among the swamps and marshes, but we know comparatively little about them. Some notion of their numbers and variety in the Triassic is gained from the innumerable footprints spread over the Triassic shore-deposits of the Connecticut River. But of all this multitude, we have actual remains of only two or three types. The *Compsognathus* skeleton of Solenhofen is, perhaps, an example of the small light-limbed upland dinosaurs of the Jurassic; *Hallopus* and *Podokesaurus* are perhaps fairly representative of their Triassic ancestors. The Jurassic sauropods, while highly specialized for aquatic life and river-bottom wading, yet retain a few features indicative of former land life. One of these is the long limbs, which it would seem must have been acquired on land. Another is the fact that the knee bends forward as it does in all other dinosaurs, while in reptiles primarily amphibious the knee bends outward and the limbs are short. The elbow of the Sauropoda, on the other hand, bends outward, as in reptiles generally, not backward, as it does in primarily quadrupedal land animals, and this

⁹⁶ F. VON HUENE: Geol. u. Pal. Abh., N. F., Bd. xiii, s. 22-38. 1914; Neues Jahrb., Beil. Bd. xxxvii, s. 577-587. 1914.

I take to be an indication that their quadrupedal gait is partly secondary and that they are derivable from long-limbed, partly bipedal ancestry. The shortening of the feet and pillar-like construction of the limbs is an obvious parallelism with the specialization of these parts seen in all large land mammals and is an adaptation to their great size. No near parallel can be found to this group among living animals; the hippopotamus affords some suggestions, but diverges widely in many respects.⁹⁷

I have already referred to the primary adaptation of the dinosaurs as a dry-land adaptation of the Reptilia. To a limited extent, the modern lizards represent a corresponding adaptation but not carried so far or occupying so important a place in the fauna. The lizards have to compete with the large and varied dry-land fauna of mammals, and relatively to these, they occupy but an unimportant niche in the terrestrial life. They suggest, however, the sort of animal which in the absence of a higher competing type evolved into the dinosaurs, and their more specialized types (*e. g.*, *Chlamydosaurus*) mimic them in proportions in a most instructive manner.

Dinosaurs are first recorded from the Triassic; those which we actually know⁹⁸ are of moderate to large size, slender and long limbed as compared with other reptiles, not highly specialized in dentition, unarmored and some but not all bipedal in gait. Indirect evidence in the multitudes

⁹⁷ See W. D. MATTHEW: "The Pose of the Sauropodous Dinosaurs," *Amer. Nat.*, vol. xlv, pp. 547-560. 1910.

⁹⁸ The principal references on Triassic dinosaurs are the following:

R. BROOM: "On the South African Dinosaur *Hortalotarsus*," *Trans. S. Afr. Phil. Soc.*, vol. xvi, pp. 201-204. 1906.

E. FRAAS: "Die neuesten Dinosaurierfunde in der schwabischen Trias," *Die Naturwissenschaften*, Bd. I, Heft 45, pp. 1097-1100. 1913.

F. VON HUENE: "Die Dinosaurier der europäischen Triasformation," *Geol. u. Pal. Abh.*, Supplem. Bd. I. 1908.

———: "Ein primitiver Dinosaurier aus Elgin," *Geol. u. Pal. Abh.*, Bd. xiv (N. S., Bd. x) Heft. I. 1910.

———: "Beiträge zur Geschichte der Archosaurier," *ibid.*, Bd. xvii (N. S., Bd. xiii) Heft. I. 1914.

———: "Ueber die Zweistämmigkeit der Dinosaurier," *Neues Jahrb. Bell.*, Bd. xxxvii, s. 577-589. 1914.

F. VON HUENE und R. S. LULL: "Neubeschreibung des Originals von *Nanosaurus agilis* Marsh," *Neues Jahrb.*, Bd. I, s. 134-144. 1908.

———: "On the Triassic Reptile *Hallopus victor* Marsh," *Amer. Jour. Sci.*, vol. xxv, pp. 113-118. 1908.

O. JAEKEL: "Ueber die Wirbelthierfunde in der Oberen Trias von Halberstadt," *Paläont. Zeitsch.*, Bd. I, s. 155. 1913.

R. S. LULL: "Fossil Footprints of the Jura-Trias of North America," *Mem. Boston Soc. Nat. Hist.*, vol. v, pp. 461-557. 1904.

———: "Dinosaurian Distribution," *Am. Jour. Sci.*, vol. xxix, pp. 1-39. 1910.

———: "The Life of the Connecticut Trias," *ibid.*, vol. xxxiii, pp. 397-422. 1912.

O. C. MARSH: "Notes on Triassic Dinosauria," *ibid.*, vol. xliii, pp. 543-546. 1892.

———: "Restoration of *Anchisaurus*," *ibid.*, vol. xlv, pp. 169-170. 1893.

———: "Dinosaurs of North America," *U. S. Geol. Sur.*, 16th Annual Report, pp. 143-244, pl. 1896.

of footprints of the Connecticut Valley sandstones shows that there must have been also a great number and variety of small bipedal three-toed forms all presumably dinosaurs, and other reptiles with shorter feet and more numerous toes which may also have been dinosaurs, although not generally so referred. Lull⁹⁹ states in regard to the latter: "These forms seem to represent survivors of the ancient stem from which the dinosaurs arose; they may, however, represent primitive quadrupedal dinosaurs which had not yet acquired the erect gait." He calls attention to their possible relationship to *Protorosaurus* and *Kadaliosaurus*.

From these and other fragments of evidence, we may reconstruct a concept of the dinosaurs as a land adaptation developed during the arid Permo-Triassic climatic phase, corresponding to the later deployments of the mammals along the same lines of adaptation and under a similar impelling cause of progressive aridity and continental expansion. During the base-leveling and submergence and moist tropical climate of the Jura, these dry-land adaptations reinvaded the swamps and coast-marshes, the least specialized types (cf. *Protorosaurus*), more quadrupedal and some of them long-necked, reverting farthest towards an aquatic life and specializing into the peculiar Sauropoda, while the higher bipedal types retained more of their terrestrial habitat but evolved into huge, massive armored and bizarre creatures, to be paralleled in habit and type at a later date by the bizarre specializations of the Eocene Mammalia. These are the familiar dinosaur fauna of the Upper Jura and basal Cretaceous. The drier uplands of that time must have been tenanted by lighter, smaller dinosaurs, but of these, in my opinion, we have little direct evidence. But that they continued to exist and carry forward their primary lines of adaptation is shown by the subsequent history of the order.¹⁰⁰

In the Lower Cretaceous occurred a swing towards emergence and arid conditions, not extreme, but sufficient to wipe out the sauropod dinosaurs in the northern world. They survived, however, in the southern continents until, in the middle and later Cretaceous, the pendulum swung back to a marked extreme of submergence and moist-tropical climate, and their remains are found in late Cretaceous beds in South America, East Africa, Madagascar and Australia. The correlation of these beds is in need of revision, however; they may be Comanchean. In the Northern

⁹⁹ R. S. LULL: *l. c.*, p. 482. 1904.

¹⁰⁰ R. S. LULL ("Dinosaurian Distribution," *Amer. Jour. Sci.*, vol. xxix, pp. 1-39, 1910) has admirably summed up the data regarding the geological occurrence of dinosaurs. While not agreeing in all respects with his interpretation, I take pleasure in noting the accuracy and clear presentation of the evidence as worthy of the high regard in which its author is held by his confrères.

world, at all events, they did not reappear after the early Comanchean. A dinosaur fauna largely similar to that of the Jurassic in habits and adaptation in other respects, developed during the late Cretaceous in the North. It contains no Sauropoda, but it includes amphibious types (Trachodontidæ) with marked aquatic adaptation, gigantic terrestrial swamp and forest dwellers, like the ceratopsians, tyrannosaurs and ankylosaurs, and many smaller more agile forms. These Cretaceous giants, however, appear to have evolved, not from amphibious or aquatic dinosaurs of the Jura, but, in part at least, from small and little known forms, of more upland adaptation, which had been much more highly specialized for dry-land life than any of the Jurassic swamp dwellers, and had readapted themselves to the forest and swamp environment of the later Cretaceous. The trachodonts and ceratopsians, for instance, while related to the earlier iguanodonts, cannot be directly derived from them but must be traced back to some unknown contemporary which was highly progressive in developing efficient grinding dentition, compact feet with flattened hoofs, etc.—characters which in a survey of mammalian adaptation we find to be especially associated with upland habitat. The evidences of former dry-land adaptation are not so clearly shown in the other swamp-giants of the late Cretaceous, but they may perhaps be shown by further study.¹⁰¹

In sum, we may find in the hypothesis of recurrent climatic change, and in the primary adaptation of the dinosaurs as a dry-land adaptation of Reptilia and their secondary readaptations to forest and swamp life, a fairly satisfactory solution of their distribution and phylogeny. Lull, in his able discussion of the subject (1910), explains their adaptation along these lines. But at present our data, both of correlation and identification, are too uncertain to allow of positive and detailed conclusions in regard to the centers of dispersal and course of migration of the dinosaurs. That the sauropods survived in the southern continents long after their extinction in the north appears proven, if we accept the stated geological correlations of the southern formations where they are found and set aside as an erroneous identification the reported occurrence of a sauropod in the Danian of France.¹⁰² That the Theropoda survived into the Eocene in South America and Theropoda and Predentata into the Paleocene in North America is not improbable on *a priori* grounds,

¹⁰¹ L. DOLLO (Bull. Soc. Belg. Géol., xix, p. 441. 1905) has shown that the quadrupedal gait of many of the Predentate dinosaurs is a secondary adaptation from bipedal ancestry. I believe this to be true, to a less extent, of the Sauropoda as well.

¹⁰² F. NOPSCH (Rep. Geol. Mag., vol. vii, p. 261. 1910) states that the femur on which this recorded occurrence is based is not a sauropod but a trachodont dinosaur, allied to or identical with Telmatosaurus of the Gosau beds of Austria.

but the evidence that they actually did so survive is open to serious question. So far as they go, the facts accord with the dispersal of the dinosaurs from the northern land mass. And so far as I have been able to review the data, the migrations of the order could be made to conform with the present distribution of continental and abyssal areas (Madagascar excepted¹⁰³) about as well as with the different distribution upon which they are plotted by Dr. Lull.

It is significant in this connection to note that young individuals are very rarely found in the dinosaur formations. Thousands of individuals are found together in some of the great quarries, pertaining to a great number and variety of genera and with a wide range in size, but it is very rare to find young individuals among them. This fact is well known to collectors, but has not, as far as I know, been commented upon in print. It is true that young individuals are less clearly distinguished from adult among reptiles than among mammals, the chief difference being the imperfect ossification of the bone structure, and that such imperfectly ossified bones are likely to be poorly preserved and might often be rejected by collectors on this account. But making all reasonable allowance for these considerations, there remains a very notable contrast with fossil mammal quarries and fossiliferous formations, in which young individuals are always to be found among any considerable number of adult specimens and often are more numerous than mature individuals.

This may be interpreted in conformity with the above theories as to the habitat of dinosaurs, by supposing that the young dinosaurs were more dry land or upland animals, retaining the ancestral habitat, and coming down into the swamps only when they reached maturity and their larger size made an amphibious or aquatic habitat more suitable. The young animals would rarely or never visit the swamps and deltas, whose formations have alone been preserved, and their fossil remains would be correspondingly scarce.

Young crocodiles, so far as I can gather from various descriptions, are somewhat more terrestrial in habit than the full-grown animal, but the difference is evidently not considerable. Analogous cases among fish, marine types breeding in fresh water and vice versa, are well known. The migration of birds has also some analogy, if, as may often have been the case, the swamp dinosaurs resorted to dry land for breeding and egg-laying purposes. In either case the breeding or egg-laying place would be presumptively the ancestral habitat of the race.

¹⁰³ The Cretaceous sauropoda of Madagascar may have reached that island in the same manner as the hippopotamus did at a later period, namely by swimming.

CHELONIA

The publication of Dr. Hay's splendid monograph¹⁰⁴ upon the extinct Chelonia of North America has added a great deal to the available data for explaining the distribution of this group. So far as the Tertiary and modern distribution goes, it conforms to the same lines of dispersal as do the various orders of mammals. The pre-Tertiary history of the order is mostly too fragmentary to afford any important data bearing, pro or con, upon the theories here presented. The whole order is in general conservative and persistent to a high degree, like the Crocodilia.

The occurrence of giant tortoises (*Testudo*) on several oceanic islands and in Australia and Patagonia (*Meiolania*) has been adduced as evidence for continental connection of these islands and for an Antarctic connection of the two southern continents. Here, as in the case of the carnivorous marsupials cited on page 265, the evidence will not bear close examination. In the first place, we know that large tortoises of the genera *Testudo* and *Stylemys* are among the most abundant fossils in the Middle and later Tertiary of the Nearctic, Palæarctic, Oriental and Ethiopian regions. So far as we can judge, they were cosmopolitan, except Australia and Patagonia. They occur in the Pleistocene of Cuba and Madagascar and survive to the present day in certain islands in the Indian Ocean and in the Galapagos Islands. So far as these oceanic islands are concerned, if we assume that their presence in one involves continental union, it must do so in all. If such continental union occurred, it is hardly conceivable that, in each instance, tortoises alone would have made their way to the islands. We must infer for each and every one of them a vertebrate and invertebrate land fauna. Where is that land fauna, and why has it perished? The idea of selective drowning might possibly be entertained if we had to do with only a single instance, but is too absurd for serious consideration, when we deal with several instances of the survival of the same race. The only reasonable method of accounting for the presence of *Testudo* on these islands is that its facilities for oceanic distribution are somewhat better than those of mammals and that it arrived by over-sea transportation.

The most recent argument for land connection of the Galapagos Islands is by Dr. Hay.¹⁰⁵ He advocates a connection with Central America, via a submerged ridge which is shown in the reports of the Blake Expedition to extend southwest from Costa Rica towards the islands.

¹⁰⁴ O. P. HAY: "Fossil Turtles of North America," Carnegie Institution Publ. No. 75, 1908.

¹⁰⁵ O. P. HAY, *l. c.*

The depth of this ridge Dr. Hay omits to state, but the soundings indicate it as being upwards of ten thousand feet, so that it does not materially affect the improbability of an elevation to this extent. The Galapagos Islands are purely volcanic in origin and stand upon a platform less than a thousand feet in depth, similar on a smaller scale to that which surrounds the continents and presumably open to similar interpretation. If so, the islands have, probably, been more or less completely united at periods of continental emergence and completely isolated at periods of continental submergence (if any such have occurred since they were first upbuilt from the ocean floor by volcanic ejectamenta) but never connected with the mainland. As the island platform is less extensive than Madagascar or Cuba, farther from the mainland and without intervening island stepping-stones, the opportunities for successful colonization through rafts or other means of transport have been fewer, and have not succeeded in introducing any mammals or amphibians and but few reptiles and invertebrates. The most favorable opportunity for such colonization would be when the islands were at their maximum elevation—towards the end of the Tertiary, if this corresponded with the elevation of the mainland—as at that time the extent of coast and consequent probability of making a landing would be much greater. The subsequent isolation of the islands by submergence accounts for the presence of distinct although related species on different islands. Thus the series of “miracles of transportation,” which Dr. Hay finds it so difficult to accept, dwindles down to a single “miracle” and to one which he must invoke to account for the populating of the more remote Pacific islands, and which, when considered in relation to the time involved, does not really involve any serious improbability. On the other hand, if a miracle be an exceptional occurrence in apparent contravention of all probabilities, and without assignable causes in natural law, I think the processes of selective drowning, or of selective migration of sporadic elements of a fauna, involved in the alternate hypothesis, in addition to the elevation during the late Tertiary of abyssal depths to the surface, unwarranted by any valid evidence, does involve a series of miracles, almost as unworthy of belief on the evidence offered, as the special creation of the species of the Galapagos Islands appeared to Darwin.

The present distribution of species of *Testudo* on the islands of the Indian Ocean has been partly changed by man, so that there is some uncertainty about its details. Lydekker states it as follows:

“Madagascar, probably the Comoros, North and South Aldabra—small islands lying to the northwest of the northern point of Madagascar—the Mascarenes

or Mascarenhas, situated to the east of Madagascar and including Réunion, Mauritius and Rodriguez and lastly the Amirantes and the Seychelles, which are the most northern of the whole assemblage and only about four degrees south of the equator."¹⁰⁸

Each of these groups of islands, except the Mascarenes, stands upon a shallow platform, and is surrounded by abyssal ocean, upwards of 5000 feet between the Comoros and Africa, elsewhere upwards of ten thousand feet. The three Mascarene islands rise separately from abyssal depths. Madagascar is about 180 miles from the African coast; the other islands are 400 to 600 miles from Madagascar; the present normal set of current is unfavorable to transportation from Madagascar.

It is very frequently asserted that a bank of shallow soundings connects India with Madagascar through the Amirante Seychelles group, and that this indicates a former continental bridge of which these islands are remnants. The facts are as above stated; the so-called bank is very little above the general level of the floor of the Indian Ocean and is not differentiated from it in any features of relief that would suggest its former continental character.

The transportation of natural rafts five hundred miles against the normal set of current—or five times that distance if from the East Indies—is the most improbable element in this explanation. There is no valid reason to suppose that the general direction of winds and currents differed materially in the later Tertiary from the present day conditions. I do not think it necessary to assume with Dr. Lydekker that the tortoises were of gigantic size when they reached the islands or to ignore, as he does, the elements of parallelism in considering their affinities to continental species. Nor does it appear that the difficulties which he admits in accounting, on the hypothesis of former continental union, for the absence of the rest of the fauna, should be "set aside for future consideration." They add so greatly to the improbability of the hypothesis, that in conjunction with the physiographic difficulties it appears wholly out of range of reasonable probability. On the other hand, an investigation of the very variable direction of the winds and currents in the Indian Ocean would probably yield data to reduce the improbabilities in the hypothesis of over-sea transportation as above stated. The third possible hypothesis is that the present distribution is due in part to human agency, not necessarily limited to the historic period. If this factor may account for a species of *Canis* in Australia distinct from the living species of *Arctogæa*, it may perhaps help to account for peculiar species of tortoises as well.

¹⁰⁸ Science Progress, October, 1910, p. 303.

As for *Miolania*, it occurs in the *Notostylops* Beds of Patagonia and in the Pleistocene of Australia. The *Notostylops* Beds are Eocene, as here advocated. The persistence of so highly specialized a genus for so long a period appears surprising; if they are Lower Cretaceous, as Ameghino asserts, it is quite unprecedented. My acquaintance with chelonian anatomy is not adequate to warrant my venturing an opinion as to how far parallel evolution from less specialized Pleurodira might account for this anomaly. But we certainly do not know to what extent this genus or a less specialized pleurodiran ancestor may have been aquatic or even marine in its habits. And unless we suppose that it had some such semi-marine adaptations which would enable it to cross a marine barrier impossible for terrestrial mammals, I do not see how to account for its reaching Australia without any of the *Notostylops* mammalian fauna accompanying it. We cannot believe that a placental fauna ever reached Australia, for if it had we should not see the development of a marsupial fauna on analogous adaptive lines to take its place. *Miolania*, then, could cross some barrier, presumably an ocean barrier, which land mammals could not; and it becomes merely a question of how wide a barrier this extinct chelonian of unknown habits could cross. The present lines of the continents within the continental shelf would not present materially greater difficulties in its reaching Australia via Antarctica than *Testudo* has managed to surmount in reaching Mauritius and the Seychelles, and I think we are justified in saying that the occurrence of *Miolania* has no weight as evidence of former Antarctic connections of the Southern continents and, in fact, is opposed to any actual land connection.

The following notes on the distribution of the land Chelonia are summarized from Dr. Hay's monograph:

Cryptodira are the dominant group of turtles and compare with the placentals among mammals. All continents except Australia.

Chelydridæ.—Central America, eastern North America and New Guinea. Apparently a relict-distribution, but the family is unknown fossil.

Dermatemydidæ.—Part of Central America. Found in abundance in North America in the Upper Cretaceous and in reduced numbers during the Tertiary.

Emydidæ.—Chiefly Holarctic and Oriental. A few have reached South America, none in Ethiopia, Madagascar or Australia. First known in Holarctic Lower Eocene.

Testudinidæ.—Very abundant in Tertiary Holarctica but now mostly restricted to its southern margin. Abundant now in Ethiopia and a few species in Neotropical and Oriental regions; also in oceanic islands. Present in Sumatra, absent in Java, present in Celebes but absent in Borneo. These and other features are very suggestive of man's having had much to do with the local extinction of Tortoises. For obvious reasons this family would be peculiarly subject to his ravages.

Pleurodira.—Now limited to the three southern continents, Holarctic in the later Mesozoic and early Tertiary, and the extinct Amphichelydia from which they are descended were likewise a Holarctic group. The occurrence of closely related genera in South America and Madagascar is used in support of a Brazilian-Ethiopian-Malagasy land connection. It would be interpreted in conformity with the views here advocated, as due to common descent or to parallel evolution from Tertiary Pleurodira of Holarctica.

Trionychida.—The distribution of this group is exceptional in that it is entirely absent from the Neotropical region and the Pacific coast of North America, while common to eastern North America, the Ethiopian, Oriental and southeastern Palearctic regions and New Guinea. Ameghino records *Trionyx* from the *Notostylops* Beds of Patagonia,¹⁰⁷ indicating if the identification be correct that the group was formerly present in South America. It is found abundantly in the Cretaceous and Tertiary of North America and in the older Tertiary of Europe; absent from Australia and Madagascar.

Presumably this is a relict-distribution of an ancient group, whose facilities for transportation were relatively limited. It should be noted that the hypothesis of over-sea transportation on rafts would be less applicable to aquatic animals than to their terrestrial relatives, as they would be less likely to be carried out to sea on floating vegetation, on account of their ability to leave it at will for the shore. But the absence of the group from the Neotropical and Western Nearctic, and its presence in New Guinea, are anomalous features.

CROCODILIA

The crocodiles are usually regarded as the most conservative of the reptilian orders. This is true enough, so far as adaptive specialization from the primitive amphibious environment into the higher plane of terrestrial habitat is concerned. Their expansional tendencies have been in the other direction, towards invasion of the marine province.

The present geographic distribution of the group is as follows:

Narrow snouted	{	<i>Gavialis</i> , India.
		<i>Tomistoma</i> , East Indies.
Broad snouted	{	<i>Alligator</i> , Southern United States, China.
		<i>Crocodylus</i> , Africa, southwest Asia, Oriental and northern Australian regions, tropical America and West Indies.
		<i>Caiman</i> , Tropical America.
		<i>Osteolemus</i> , West Africa.

This is very clearly a remnant-distribution and is explained, at least in part, by the occurrence of crocodiles in the Tertiary. Fossil Crocodilia are abundant in the early Tertiaries of Europe and North America. The European species, according to Zittel,¹⁰⁸ belong partly to *Crocodylus*,

¹⁰⁷ FL. AMEGHINO: "Age des Formations Sédimentaires de Patagonie," Anal. Soc. Cient. Argent., tom. I, LIV, p. 52 of separata. 1903.

¹⁰⁸ K. A. VON ZITTEL: Grundzüge der Paläontologie, 2e Aufl., II Abteil., s. 272. 1911.

partly to the extinct genus *Diplocynodon*, in which the proportions of the skull are like *Alligator*, but with a notch for the lower canine, like *Crocodylus*, while the armor, especially the belly armor, is like that of *Caiman*. North American Tertiary Crocodilia are all with one exception referred to *Crocodylus*, but the armor is incompletely known, and they may prove also to include *Diplocynodon*. *Gavialis* is recorded from the late Tertiary of India; *Tomistoma* and *Crocodylus* occur in the Oligocene of Egypt and *Tomistoma* in the Miocene of southern Europe. The common Egyp-

FIG. 82.—Distribution of the Crocodilia

Originating probably in Cretaceous Holarctica, they have been restricted to the peripheral continents by inability to become adapted to cold climates. Note discontinuous occurrence of crocodiles and of alligators, the last the most specialized, as *Caiman* and *Osteolemus* are the most primitive of the living genera.

tian Oligocene species of *Tomistoma* is intermediate between this genus and *Gavialis*.

The Upper Cretaceous crocodiles are nearly allied to those of the early Tertiary.

The Jurassic and Comanchic crocodiles include also long-snouted gavial-like forms, more or less marine in habitat, and broader-snouted crocodile or alligator-like forms of more strictly fresh-water habitat. All

have amphicœlous vertebræ, whereas all Cenozoic and late Cretacic crocodiles have procœlous vertebræ. It is commonly believed that certain of the narrow-snouted types (*Teleosaurus*) led into the gavials, the broad-snouted (*Goniopholid*s) into crocodiles and alligators; and that the broad-snouted types first appearing in the Upper Jura are derived from the teleosaurs which first appear in the Middle Jura. Neither of these propositions seems to me to be probable. The narrow-snouted crocodiles are characteristic of marine or semi-marine formations, the broad-snouted kinds of fresh-water formations; the known formations of the Middle Jurassic are chiefly marine, those of the Upper Jura chiefly fresh-water.

If we turn back to the Trias, we find that in the allied Parasuchia there were also long-snouted (*Mystriosuchus* and *Rutiodon*) and broader-snouted (*Belodon*) types—both of fresh-water habitat, but apparently less aquatic than *Crocodylia*; in the allied Pseudosuchia the snout was short, and the adaptation to amphibious or fresh-water life; while the more distantly related dinosaurs were terrestrial and short-snouted. Upon these data, it appears to me more reasonable to suppose that the Triassic *Mystriosuchus* and *Rutiodon*, the Jurassic Geosauridæ, Teleosauridæ and Metriorhynchidæ and the Tertiary Gavialidæ are all independent successive adaptations to a fish-eating diet and a more or less marine habitat and that the Jurassic Goniopholidæ are the source of all the modern *Crocodylia*. This will also relieve us from the necessity of supposing that procœlous vertebræ and a number of other identical characters were independently and simultaneously acquired in two phyla of diverging adaptation. The accepted view involves the anomaly of associating divergent adaptation with convergent structural evolution.

However this may be, we are justified in assuming certain characters as primitive among the modern *Crocodylia*, since they are common to all the older types. These are the following:

1) More complete and consolidated ventral armature. Common to all the Mesozoic genera, retained in *Diplocynodon* of the European Tertiary and the modern *Caiman* and *Osteolemus*.

2) A notch instead of a pit in the upper jaw for reception of the lower canine. Common to all the short-snouted crocodiles of the Mesozoic and Tertiary, retained in the modern *Crocodylus*.

3) Amphicœlous vertebræ. Common to all *Crocodylia* and related groups up to the middle Cretaceous, lost in most Upper Cretaceous and all Tertiary¹⁰⁰ and modern genera.

4) Large supratemporal and small lateral temporal fenestræ. The upper temporal fenestra is large in all Mesozoic *Crocodylia*, considerably smaller in the gavials, quite small in *Crocodylus*, *Alligator* and *Caiman*.

¹⁰⁰ Except *Notosuchus* of the Patagonian Eocene.

5) Posterior nares more anterior in position. In the Mesozoic crocodiles, the choanæ are situated at the posterior end of the palatines in the long-snouted groups, while in the short-snouted Goniopholidæ, they have moved further backward, between the palatines and pterygoids. In the modern Crocodilia, they are still farther backward, entirely enclosed within the pterygoids. This is an adaptation to lying submerged with the nostrils only projecting above the surface of the water and enables the animal to breathe comfortably in this position. It would naturally develop in the slow, omnivorous broad-snouted crocodiles and not in the swift-moving fish-catching, long-snouted types; hence its greater development in Goniopholidæ than in teleosaurs, etc. The fact that it is fully as much developed in gavials as in crocodiles is another reason for deriving both from Goniopholid ancestry.

According to the above criteria, *Alligator* is the most progressive modern genus.¹¹⁰ *Caiman* is primitive in (1); *Osteolæmus* in (1) and (2); *Crocodilus* in (2) and to some extent in (4); *Gavialis* and *Tomistoma* are primitive in (4), divergent in adaptation in other respects, so that comparisons would be unprofitable. We may conclude, therefore, that so far as they go, the Crocodilia accord with the general lines of distribution of other groups. They ranged much farther north during the Tertiary than they do now; the most progressive modern genus, *Alligator*, has the most northerly range, and the Neotropical *Caiman*, the West African *Osteolæmus* and the cosmopolitan tropical genus *Crocodilus* are primitive in one or another respect. The gavials also had a wider and more northerly distribution during the Tertiary.

That the present limits of range are conditioned chiefly by temperature and climate, and that the much wider range in the early Tertiary was due to a warmer climate towards the poles, will hardly be questioned. Of previous limitations and expansions of range in the order, due to previous secular alternations of climate, there is no adequate evidence. The distribution of the more primitive modern genera in widely separated parts of the tropics; the occurrence of the most progressive genus on the northern borders of the range of the order in two widely separated regions, and, finally, the survival in the Eocene of Patagonia of a crocodile, *Notosuchus*, of the Mesozoic type which had disappeared from the Northern world by the Middle Cretaceous,—these facts point to a northern rather than a tropical or southern center of dispersal for the order; but the evidence is slight and far from conclusive.

¹¹⁰ R. L. Ditmars, of the New York Zoölogical Park, has observed that crocodiles are decidedly more active and ferocious animals than alligators. I would not interpret this, however, as meaning that they are more progressive, in the sense here used, since the adaptation of the typical Crocodilia is not towards an active life.

LACERTILIA

Lizards are the largest group of the Reptilia, comprising over 1800 species, mostly of small size. Most of them are active animals, and a large proportion are adapted to rocky and desert habitat and arid climate. They are more dependent on external warmth than mammals and birds, and consequently are excluded from the colder regions; their means of dispersal are perhaps less limited than with mammals, if we may judge from their wider distribution, for they do not appear to be of more ancient origin. Unfortunately, the rarity and fragmentary nature of their fossil remains stands in marked contrast with those of mammals, and our evidence as to their evolution and dispersal is chiefly indirect, based upon the modern distribution, and is neither conclusive nor convincing. Such as it is, it compares fairly well with corresponding distribution features among the smaller Mammalia and points to the same conclusions. But it emphasizes the importance of occasional over-sea transportation as a factor in distribution. Gadow observes¹¹¹ in regard to the Geckos, the most cosmopolitan of all lizards:

"Although not at all aquatic, they are particularly fit to be transported accidentally on or in the trunks of floating trees, to which they cling firmly, and they can exist without food for months."

Other groups are somewhat less easily transported in this way, and to quote the same authority:

"It is a most suggestive fact that most of those families of Reptiles, and even of other vertebrates which have a wide distribution and are apparently debarred from transgressing Wallace's line, are also absent from Madagascar."

The iguanas are chiefly Neotropical, but they occur also in Madagascar, in the Fiji and Friendly Islands and in the West Indies and Galapagos Islands, as well as on the American continent. Fossil iguanas are recorded from the Upper Eocene and Oligocene of Europe and from the Upper Cretaceous and Middle Eocene of the western States. If these determinations be correct, they must formerly have been more cosmopolitan. Their presence in Madagascar is most reasonably explained by their former presence in Africa, which is rendered probable by the fact that they occur in the early Tertiary of Holarctica, along with various mammalian groups which certainly did reach Africa. Their disappearance from the mainland of Africa may be coupled with the invasion of other later developed groups, Zonuridæ, Varanidæ, Lacertidæ, which

¹¹¹ HANS GADOW: Cambridge Natural History, vol. viii, Amphibia and Reptiles. 1901. The distribution data for lizards and amphibians are mostly based upon this authority.

were prevented from reaching the New World by the absence of any land bridge or land approximation within their temperature limits. One genus of Zonuridæ has likewise reached Madagascar.

Bearing in mind the progressive limitation of northerly range of the Lacertilia by the secular refrigeration of the polar regions during the Cenozoic, we can see that, if the distribution of land and water has not greatly changed except within the 600 feet limit, any families arising during the middle or later Tertiary would be limited to the old or to the new world. While the distribution of various lizards in oceanic islands compels us to admit that they can cross considerable bodies of water and obtain a foothold on an imperfectly populated island area, yet the probabilities of their crossing the whole width of a broad ocean and maintaining themselves against competitors trained in the broad arena of a great continent appear to be very much less and almost negligible. Conversely then, we may assume that a distribution, such as that of the Scincidæ, Iguanidæ, Geckonidæ, Anguidæ and Amphisbænidæ, involves the evolution and cosmopolitan distribution of these families as early as the Eocene. The Agamidæ, Varanidæ, Lacertidæ, Zonuridæ, Chamæleontidæ are Old World families, and none are known from the New World. The Zonuridæ may well be regarded as of Ethiopian evolution; if not, they must be a remnant of a very ancient stock. The same may be said of the Chamæleons, except that if Ethiopian they reached as far as India. The Lacertidæ, the highest, or at least most typical family of lizards, are evidently the most recent development; they have not yet reached Madagascar or Australia, and their northern limit is higher than in any other lizards. The Varanidæ and Agamidæ have not reached Madagascar but have spread widely through Australia. The evidence from extinct lizards is very slight, the remains are scanty and mostly too fragmentary for positive family identification. Of the several genera from the Eocene and Oligocene of North America, two are positively referable to the worm-like Amphisbænidæ, whose present distribution in tropical America, the West Indies and Africa is thus partly explained as a remnant of a former wider northerly range and presumably Holarctic. Of the remaining North American Tertiary genera, *Peltosaurus* and *Glyptosaurus* are referred to the Anguidæ;¹¹² the remaining genera are too fragmentary for reference or have not been studied.¹¹³

¹¹² EARL DOUGLASS: Ann. Carn. Mus., vol. 4, p. 278. 1908.

¹¹³ The recorded presence of Iguanidæ (*Iguanavus*) in the Cretaceous and Eocene, while not provable, is not unlikely; that of *Chamæleon* (*C. pristinus*) in the Upper Cretaceous is improbable and based upon insufficient evidence; the reference of *Thinosaurus* (Middle Eocene) to the Varanidæ appears to be merely a matter of bibliographic convenience; the specimens are probably definitely referable, but the only expressed opinion as to their affinities is by Boulenger (1891), who suggests their relationship to the Telidæ.

In general, so far as I can judge, the Lacertilia lend no support to the theories of transoceanic bridges. Their widespread insular distribution must in some cases, and may in most others, be explained by over-sea transportation. They lend some support to late Tertiary elevations to the continental shelf line so as to include the continental islands and to a line of separation in the East Indies which some, but not all, were able to cross; those which did succeed in crossing it spread widely through Australia, indicating more continental conditions, and also indicating in these families a capacity for crossing marine barriers which enabled some of them to reach Madagascar, New Zealand and various Pacific islands.

The ratio of their abundance in regional faunæ is apt to be inversely to the full development of mammalian life. Where mammals are scanty, as in oceanic islands, lizards partly take their place; and this is true of some continental regions as well as of oceanic islands. In the typical continental fauna, the lizards are largely restricted to desert or rocky habitat and are of small size. Yet these last are the most typical members of the order. They show what its primary adaptation was. Various readaptations appear, to fossorial, to aquatic, to arboreal or to terrestrial forest life, repeated again and again in different families and causing frequent parallel divergencies from the primary type. This primary type, I regard as an adaptation to a Mesozoic arid period. The moist uniform climatic phase of the early Tertiary would tend to develop large forest living and aquatic forms and restrict and provincialize the more typical lizards. During the middle and later Tertiary, the typical lizards would expand and multiply in numbers and variety, but, on account of their lack of adaptability to cold climate, their evolution was not so much a successive series of dispersals from a Holarctic center, as a provincial evolution from the arid centers of the great continents. Such *à priori* hypotheses are of little value, however, except as confirmed, modified or refuted by detailed study of the affinities and geographic distribution of the genera of each family, checked by a wider knowledge and more thorough study of the fossil forms. Until the fossil Lacertilia have been thoroughly studied and their affinities authoritatively estimated, any conclusion whatsoever as to the evolution and distribution of the order remains highly hypothetical.

Dr. Gadow's recent study¹¹⁴ of the distribution of *Cnemidophorus* and its interpretation is an excellent example both of the value of such detailed studies and the need of carefully distinguishing between what the

¹¹⁴ H. GADOW: "A Contribution to the Study of Evolution based upon the Mexican Species of *Cnemidophorus*," Proc. Zool. Soc. London, vol. 1, pp. 277-375. 1906.

data themselves indicate and what is assumed as true from other evidence. He concludes,—

- 1) That the species are the product of their environmental conditions;
- 2) That their dispersal center was in western Mexico, whence they have spread northeast as far as Texas and Florida, southwardly into South America, northwestwardly into Lower California;
- 3) That the primitive type was nearest the Texas and Florida species.

He assumes—evidently on some other grounds—

- 1) That a great land area stretched out from Mexico far into the Pacific during the Tertiary all the way between Lower California and Central America;
- 2) That the central tableland of Mexico was a vast fresh-water lake during most of the Tertiary;
- 3) That Cuba was connected with the American mainland during the Oligocene (this assumption underlies the statement that, since the Floridian *Cnemidophorus* did not reach Cuba, its migration must have occurred as late as Miocene).

Ortmann,¹¹⁵ reviewing this paper, takes, as proven by Gadow's studies, not merely the points actually indicated but also the assumptions which are entirely unnecessary to explain the data but which Dr. Gadow evidently feels obliged to take for granted. In fact, these assumptions interfere with a reasonable interpretation rather than help it, and all of them are questionable, to say the least. The great Tertiary lake is, I suspect, on all fours with the vast interior "lakes" of the Plains region of the United States, which the progress of physiographic and paleontologic studies have relegated to the domain of myth. The connection of Cuba with the mainland of either North or South America involves the same difficulties as the connection of Madagascar with Africa. The recent discoveries by Dr. de La Torre of a Pleistocene vertebrate fauna in Cuba strongly confirm this analogy between the Cuban and Malagasy faunæ. The existence of extensive land west of the present Pacific coast line is an equally unnecessary and improbable hypothesis. On the other hand, Dr. Gadow fails to take into account the barrier between North and South America which prevented or hindered intercommunication of land faunæ during a large part of the Tertiary, while it permitted intercommunication of marine faunæ during the Eocene. I am not here concerned with its nature but may venture to point out that its bearing on the differentiation of species would be important. For, once across that barrier, an invading species would find itself in unfamiliar environment on account of differences in the autochthonic fauna and flora, even

¹¹⁵ A. E. ORTMANN: Geog. Jahrb., vol. xxxi, p. 262. 1908.

though the physical environment were similar. If the rising of the Mexican tableland conditioned the dispersal of the genus from that center, we can see in this different biotic environment the reason why the marginal species in North America should be primitive, while the marginal species in South America are highly specialized. In general, it would be true that the species of the dispersal center (or those nearest to it, where, as in this case, it has become ill adapted for the habitat of the race) will be the most progressive and those of the marginal areas nearest the primitive stock. But where the scattering primitive forms, in following the primitive climatic conditions, are brought into a new floral and faunal environment, this may profoundly modify them and cause a rapid divergence and specialization.

DISPERSAL OF BIRDS

As a class, birds are extremely difficult in their taxonomy. They are held closely to type in comparison with mammals, and the differences between them are mostly directly and obviously due to adaptation. Adaptive parallelism obscures the true affinities to such an extent that even at the present day the major classification is somewhat uncertain. This difficulty is the greater on account of their rarity as fossils. There is no reason to interpret this rarity as indicating any lack of abundance of birds in the faunæ of Tertiary and later Mesozoic time; it is presumably to be accounted for by their generally upland habit, small size and the lightness and fragility of the skeleton. The small minority of fossil birds which are known from anything more than a few fragments are, with two or three notable exceptions, aberrant types—ground-birds, marine or lacustrine types, whose habitat facilitated their preservation as fossils. By far the most notable and instructive of these exceptions is *Archæopteryx*.

It has been customary to class the greater number of the ground-birds (Ratitæ) as a more primitive sub-class. On *à priori* grounds, this may be correct enough, since it would appear theoretically that feathers must have preceded flight, the ability to fly being conditioned by high organization plus small size, and this would involve a rapid circulation and high temperature, which could hardly be attained without a nonconducting coating over the body. But it appears certain that most, and possible that all of the existing ground-birds are readaptations to terrestrial habitat from flying ancestors, and their resemblances are due almost wholly to adaptive parallelism.

Owing to their powers of flight, the dispersal of birds is much less

limited and conditioned by distribution of land and water or by mountain or desert barriers than is that of mammals. Climate and environment are much more important factors. Their dispersal is accordingly much wider, and this is especially true of the more migratory and strong-flying types. The general course of their dispersal from the northern land masses is in some respects much more obvious than with the *Mammalia*, provided we allow for the extreme imperfection of their geological record; but on this account, it is not supported by the mass of direct evidence which we have among mammals.

The most primitive living birds, the penguins, are Antarctic in their distribution, and as fossils are known only from the Antarctic Tertiaries, where they include gigantic terrestrial adaptations. It is of interest to note that the only actually known land vertebrates of the Antarctic continental area are penguins. If this continent had been united during the late Mesozoic and early Tertiary to Australia and South America, we should expect to find a fossil mammal fauna, probably highly progressive and specialized before the spreading ice swept it out of existence. We might, indeed, hope to find a few marine adaptations from this mammalian fauna still haunting the edges of the Antarctic pack. But in fact, the three items which to my mind have a bearing upon early Tertiary conditions in Antarctica all point towards continued isolation and obviously parallel the fauna of oceanic islands. These are,—

1) Gigantic land-penguins in the ? Eocene deposits of Seymour Island (also in Patagonia). Compare with the gigantic land birds of various oceanic islands, correlated with paucity or absence of land mammals.

2) The living marine penguins are not readily interpreted as a primarily marine adaptation, but they are very easy to understand as modified survivors of a group formerly of terrestrial habits, altered to meet the present conditions under which alone could life be maintained on the Antarctic shores.

3) The occurrence of *Miolania*, as interpreted on page 283, is suggestive of the former presence of giant land-turtles in Antarctica, although not explainable as evidence of former land connections with South America and Australia.

There may be other indirect evidence in the distribution of marine *Vertebrata* and *Invertebrata*, which, if conservatively interpreted, would confirm or disprove these indications. So far as they go, they suggest that ground-birds and land-turtles were the large land vertebrates of Tertiary Antarctica as in oceanic island faunæ of to-day.

The distribution of modern land birds is universally interpreted in

terms of Northern derivation. Oceanic, desert or mountain barriers have been much less efficient in limiting their range, and the efficiency of the climatic factor is much more obvious than with mammals. Their dispersal from a Holarctic center in successive waves of migration is indicated by the dominantly Holarctic habitat of the highest and latest developed groups, by the generally tropical habitat of archaic groups often highly specialized, whose ancestors or relatives are in many cases known from the Holarctic Tertiary, and by the fact that the southern continents are peopled, not by a series of dominant groups corresponding to the Holarctic groups, evolved in a common Antarctic center, but chiefly by groups of more or less tropical affinities and by a few northern groups which have crossed the tropic barrier. There are many groups of birds living to-day in the widely separated tropical regions whose ancestors have not thus far been discovered in the Holarctic Tertiary. But they correspond, both in distribution and in relative position in the classification, with other groups which the geologic record proves to have originated by dispersal from Holarctica, and there is no valid reason for assuming any other origin. The geologic record of Tertiary birds is far more fragmentary than that of Tertiary mammals and especially in the Nearctic region.

It should further be observed that the perching birds represent the primary adaptation from which the various specializations—terrestrial, wading, marine, etc.—have diverged, and that, in consequence, these divergently specialized forms retain various archaic features which have been lost by the central group.

The relations, dispersal and present distribution of birds are thus wholly in accord with the principles here set forth. The detailed application of these principles is beyond the limits of the present discussion.

DISPERSAL OF AMPHIBIA

The modern Amphibia include a few small and for the most part highly specialized survivors of a group whose period of dominance dates back to the Paleozoic. Of their Mesozoic and Tertiary ancestry almost nothing is known. The Stegocephalia, the dominant Amphibia of the Permian, were far less aberrant and much nearer to the contemporary primitive Amphibia; their interrelationships are still far from being precisely definable, and, until these are better understood, it is futile to discuss the evidence which they may furnish as to former geographic connections.

The distribution of the modern Amphibia is often notably discontinuous, and in the absence of evidence from extinct types as to the real

origin of these discontinuous distributions they are interpreted by many authors as affording evidence for various transoceanic bridges. But they are not essentially different from various instances of discontinuous distribution among Mammalia, except that they are probably in some cases of more ancient origin, and are less restricted by ocean barriers.

The urodele Amphibia are Holarctic, save for one family, Plethodontidæ, which has spread into northern South America and has also reached Hayti. Although thus limited in dispersal, they would seem to be an ancient group represented as far back as the Wealden by *Hylæobatrachus*, said to be related to the modern *Cryptobranchus*.¹¹⁶ Their distribution within Holarctica is more or less of a relict type, broken up by the unfavorable environment of so large a part of this region, especially of the central portion. The cæcilians are tropical but have not reached Australasia.

The frogs and toads have a wide dispersal, and so far as a superficial view may show, the most primitive or archaic families are limited to the peripheral continents and oceanic islands, while the more progressive groups are more cosmopolitan, but have not yet reached all of the outlying regions. Some of the families, at least, would appear to be of ancient origin; *Palæobatrachus*, allied according to Gadow¹¹⁷ to the *Aglossa* of the Ethiopian and Neotropical regions, is recorded from the Jurassic of Spain, and is said to be common in the older Tertiary of Europe. Among the modern families the Cystignathidæ are chiefly Australasian and Neotropical, but a few are still found in North America. This distribution parallels that of the polyprotodont marsupials, except that the latter have not reached New Zealand or the Antilles, or entirely disappeared from the East Indian islands. The Discoglossidæ inhabit the East Indies and North America but have disappeared from the intervening portion of Holarctica; *Discoglossus* and other genera are found in the Middle Tertiary of Germany. The Pelobatidæ stretch across Europe and Asia and northwestern North America. These three families represent evidently three successive dispersals.

The other families are more cosmopolitan. The genus *Bufo* has failed to reach Australasia, Madagascar or New Zealand, but is replaced in Australia by a (more primitive?) member of the family. The Hylidæ are to-day chiefly South American and Australian, but a few members still inhabit North America. They are not found in Africa or the Oriental region, where it seems reasonable to suppose that they have been displaced by the true frogs (Ranidæ), peculiarly varied and abundant in

¹¹⁶ F. BROILI, in Zittel's *Grundzüge der Palæont., Vertebrata*, s. 176. 1911.

¹¹⁷ H. GADOW: *l. c.*, p. 145. 1901.

these regions. The Ranidæ, like the Bufonidæ, represent a less ancient dispersal, probably from a southern Palearctic or Oriental center, since they have reached northern Australia on one side and northwestern South America on the other, and, while they have reached Madagascar and the Solomon Islands, they have failed to reach the Antilles.

These suggested lines of dispersal are based upon the present distribution interpreted in accord with the principles outlined in previous pages of this article. While the past history of the Amphibia is too little known

7

FIG. 33.—*Distribution of three families of Anura*

These may be interpreted as due to three successive dispersals from the north. The other families of frogs and toads are more widely spread, and their regional abundance has conditioned certain peculiarities in the distributions here shown.

to confirm them by adequate direct evidence, I believe that good inferential evidence might be obtained from a comparison of the progressive or archaic characters of the skeleton in the different families. The fossil Amphibia afford sufficient evidence to determine the broader lines of their evolution and differentiation, although they tell very little about their past distribution. The same conditions hold true with regard to the fresh-water fishes.

DISPERSAL OF FRESH-WATER FISHES

The fresh-water fishes afford many striking illustrations of isolated primitive survivals in the southern continents and especially in their tropical parts. With marine fishes, the distribution is wider, as we should expect, and the dominant types are generally world-wide in their distribution. Yet, even with marine fishes, a superficial survey seems to show the majority of primitive survivals along the southern coasts.

Fishes are, it is to be remembered, dominantly marine. The wider field and more varied opportunities for development afforded by the ocean waters, in contrast with the limited and isolated fields and uncertain tenure afforded by fresh-water rivers and lakes, have conditioned this. The fresh-water habitat for aquatic groups of animals stands in somewhat the same relative position to the marine habitat as does the insular to the continental habitat for land animals. It is the refuge for survivors of primitive faunæ. And, as in the insular land faunæ, we are constantly confronted there with the occurrence in widely remote regions of archaic types apparently nearly related, whose similarity is partly due to independent adaptation to a similar environment, partly to persistent primitivism.

Lepidosiren in tropical South America, *Protopterus* in tropical Africa, *Ceratodus* in tropical Australia are perhaps the most prominent examples of extremely ancient survivals. These are survivors of early Mesozoic or even Paleozoic marine and estuarine fishes of world-wide distribution, and they have endured, in their tropical refuge, the several successive periods of zonal climate which affected the environment of temperate and tropical regions.

More pertinent to the problem in hand are the relationships of early Tertiary fishes of the northern continents to the modern South American, African (and Australian?) fishes. Here, again, I am compelled to dissent from the interpretations and conclusions of so distinguished an authority as Dr. Eigenmann,¹¹⁸ who, as it seems to me ignores certain very important parts of the evidence.

There is a marked similarity between certain parts of the fresh-water fish faunæ of South America and of Africa. Eigenmann and others would explain this by a former continental union, but it is certain that some, at least, of these now tropical types existed in the northern continents during the early Tertiary. Eigenmann¹¹⁹ asserts, indeed, that no

¹¹⁸ See especially C. H. EIGENMANN: "Fresh-water Fishes of Patagonia," Reports Princ. Univ. Exped. Patagonia, vol. III, parts III-IV. 1909-10.

¹¹⁹ C. H. EIGENMANN: Popular Science Monthly, 1906, p. 523.

part of the modern South American fresh-water fish fauna is derived from North America; but how he reconciles this with the recorded presence of several of the most typical genera in the Green River Eocene of Wyoming, I do not see.

A few cases in point may be noted, as follows:

Lepidosteus, now Central American and southern Sonoran. Abundant in all the Eocene formations of the northwestern States, as also in Europe.

Phractocephalus, *Arius*, etc., now South American, nearly related to *Rhineastes* of the Bridger and *Amyzon* beds of the western States.

Osteoglossus of Brazil, Borneo and New Zealand, *Vastres* and *Heterotis*, also southern types, closely related to *Dapedoglossus* of the Green River shales (Eocene).

The characins, which form so important an element of the modern South American fauna, are, as Eigenmann holds, largely a local expansive radiation conditioned by the immense ramifying river-systems of that continent. But, considered in their more general relations, they are a primitive group, the northern cyprinids being a higher and later development.

The catfish, which in the North have the characteristics of a disappearing group, are numerous and dominant in South America. Eigenmann calls attention to the paucity of the Patagonian fauna and its apparent relations to that of New Zealand and Australia (Galaxiidae and Aplochitonidae). He does not, however, attach any great weight to this as evidence for a former Antarctic connection, regarding it as "highly theoretical and precarious" so far as the fresh-water fish are concerned—but "The evidence from other sources of a former land connection has become conclusive." I might observe here that many students in other groups are equally doubtful of the conclusiveness of the evidence for Antarctic connections in the groups with which they are familiar, while equally ready to accept as conclusive the evidence in groups with which they are not familiar.

As regards a connection of tropical Africa with tropical South America, Eigenmann is much more positive, basing it mainly upon the characins and cichlids, common to both continents. There is no species or genus common to the two continents. Both families are relatively primitive, as compared with northern related groups. As regards their former presence in the northern world (which Eigenmann does not allude to) or their parallel adaptation from marine forms of Cretaceous or early Tertiary time, there is little satisfactory evidence. Nevertheless, the fact that they represent an adaptive divergence from an intermediate and more primitive type ancestral to carp and catfish is a suggestive one.

If now we compare the general relations of tropical fresh-water fishes with those of the North, it will appear very clearly that the highest and latest in appearance of the several groups are still limited to the northern world, and that, in the tropics, more primitive groups exist, many of them known to be former residents of the northern world, others much nearer to known or inferred ancestral groups than are any members of the present northern fish fauna. Where the environment favors, some of these groups have branched out into an immense variety and number, far exceeding what is known in the colder north. But they are distinctly less progressive. In the southern continents, we meet with some remarkable parallelisms to the dominant types of the North, very suggestive at first of Antarctic connections, but probably explainable (as in *Galaxias*) in other ways. These groups impress one as highly progressive, although less so than the northern groups; but they do not appear to have contributed materially to the tropical faunæ.

In some respects the fresh-water fishes present nearer analogies to the birds than to mammals in their distribution; and this is no doubt conditioned by their less strict limitation to land connections for their migration, and to the greater antiquity of the class.

GENERAL CONSIDERATIONS ON THE DISTRIBUTION OF INVERTEBRATES AND PLANTS

It would be unwise to attempt any survey of the paleogeographic data afforded by invertebrates and plants. Lacking both the special knowledge necessary for a critical consideration of the data, and the time necessary to make even an adequate compilation, it would add nothing to the argument. While, for reasons already given (page 272), placing most weight on the evidence obtainable from mammals, I fully recognize the importance and variety of evidence outside the Vertebrata, and the force which attaches to cumulative evidence from several independent sources. At the same time I must express a strong conviction that the sources are not really independent, and that concordant results in several groups which flatly contradict the results obtained by a study of mammals, can only indicate one of two things. Either the interpretation of the evidence among the Vertebrata is incorrect or there are factors of error common to the interpretation of the several other groups which accord in their disagreement. What these factors may be, I have already indicated and have attempted to show that they account for discordant results based upon the distribution of the lower vertebrates and interpreted as involving radical changes between continental and abyssal regions which

are highly improbable, to say the least, from a geological point of view, and which are not merely unnecessary but apparently impossible when we attempt to explain the distribution of the higher vertebrates in accordance with them.

It is true that the evidence against such changes in pre-Tertiary times is less weighty, and that it diminishes further in the older periods of geologic time. And the antiquity of many groups of invertebrates, especially of land invertebrates, makes it impossible to limit the hypothetical land bridges which their distribution is supposed to require, to the Tertiary or even the Mesozoic. The permanency of the ocean basins in the older geologic epochs is beyond the limits of this discussion.

So far as a superficial acquaintance shows, the general distributional relations of most land invertebrata and of plants appear to me to accord with those of the mammalia. Primitive and archaic¹²⁰ types abound chiefly in the tropics. The most progressive and dominant types are Holarctic. The southern continents show common groups suggestive of an Antarctic radiation, but which may, like the marsupials or the chrysochloroid insectivores, be remnants of formerly cosmopolitan groups whose resemblance is due rather to persistence or to parallel evolution under similar climatic stimulus than to such close affinity as would involve Antarctic continental connections.

Where, as in the earthworms, we have no knowledge at all of their past distribution, it is impossible to test this interpretation of their present distribution; nor in such a group does it seem possible to estimate how much and in what manner slow progressive climatic change might affect their structural evolution, although climatic conditions are evidently important in controlling their range.

The point that I desire to emphasize is that, if such an interpretation as I have suggested be possible, it should be accepted in preference to one which would involve such unexplainable difficulties in the distribution of the higher animals and such improbable physiographic changes. No hypothesis can be finally accepted that does not conform to the facts of distribution in all groups of animals and plants. It is not a matter of preponderant evidence. Every anomaly must be explained, every distributional fact must be interpreted in accord with the rest, before we can consider theories of paleogeography as conclusively proven. It is not sufficient that the evidence in one group or in ten groups has been interpreted on concordant lines, so long as there remains an eleventh group which cannot be so interpreted. But, pending a final agreement

¹²⁰ Archaic is used in the sense of divergently specialized but little progressive.

in our deductions from the evidence afforded by the various classes, it appears to me that we should hold to conservative views rather than adopt hypotheses of continental relations so much at variance with generally accepted geological principles and inferences.

To illustrate the point that these discrepancies are a matter rather of interpretation than data I may venture to discuss one or two instances among invertebrates prominently used in paleogeography.

INTERPRETATION OF DISTRIBUTION DATA OF CRAYFISH

I am indebted for my data on this interesting group to Dr. Ortmann's valuable discussion of the geographical distribution of fresh-water Decapoda.¹²¹ The interpretation, however, which I would place upon the facts differs widely from his.

As Professor Huxley has observed, the real difficulty in explaining the distribution of the crayfish is in their occurrence in the north and south temperate zones, separated by a wide tropical belt in which none now occur or are known to have occurred in the past. Two explanations offer themselves:

1) Independent adaptation from marine types in the northern and southern hemispheres. This would involve either former Antarctic connections or independent adaptation also of the several southern groups from marine types.

2) Former cosmopolitan distribution of crayfish, with subsequent disappearance from the tropical belt and differentiation of the isolated southern groups and of the more progressive northern groups.

The latter view is generally accepted, and seems to me more consonant with the facts of distribution, *e. g.*, presence of crayfish in Madagascar, while they are absent from South Africa. I am unable to agree with Dr. Ortmann that crayfish on oceanic islands necessarily involve a former land connection, since such land connections as he finds it necessary to postulate would apparently involve the presence on these islands of continental faunæ which are not now present, and whose absence cannot be reasonably accounted for. For the reasons already presented I see no difficulty in supposing that the crayfish of Cuba, Madagascar, New Zealand or Fiji have reached those islands by accidental transport of natural "rafts" through the agency of ocean currents, or by other accidental means. The Australian and South American crayfish I should regard as derived from the north, by way of the existing or slightly sub-

¹²¹ A. E. ORTMANN: "Geographical Distribution of Fresh-water Decapods and its Bearing upon Ancient Geography," *Proc. Amer. Phil. Soc.*, vol. xli, pp. 267-400. 1902.

merged land bridges, at a time when the northern crayfish were much more primitive than now, and when, for reasons which I do not venture to suggest, the tropics were a more favorable environment than now. The northern crayfish have since evolved into *Potamobius* and *Cambarus*, the southern specialized into the more divergent *Parastacus* of South America, *Cheraps* and *Eugæus* and *Astacopsis* of Australia and Tasmania, *Paranephrops* of New Zealand and ? Fiji and *Astacoides* of Madagascar.

Of these southern genera, *Astacoides* is the nearest to the northern types. This is to be expected, if the southern genera are remnants of a cosmopolitan distribution derived by dispersal from the north; for the Malagasy genus would be a derivative from Ethiopian crayfish, which would be less remote from the north, and would be correspondingly more advanced than in South America or Australia. As far as the more special distribution of the northern crayfish is concerned, Dr. Ortmann's paper affords data for the following interpretations.

Two genera are concerned, *Cambarus* of the eastern Sonoran region, and *Potamobius* (*Astacus* of most authors) of the Old World and western Sonoran region.

In his discussion of the genus *Cambarus* Ortmann states that the more primitive forms of the first, second and fifth groups belong chiefly to the south towards Mexico, and interprets this as meaning that the genus came from Mexico. But, according to the principles here adopted, this should mean that the center of dispersal is to the north and east; and the discontinuity in range to the south and west is exactly what we should expect, Dr. Ortmann's attempt to find an explanation for it on the opposite theory of migration being curiously complex and unconvincing. The most primitive species occur in such widely divergent points as Mexico and Cuba.

The more primitive genus *Potamobius* has a more discontinuous range, in Europe, part of Eastern Asia and Western North America, the Asiatic species being nearest to *Cambarus* (i. e., highest in development) but parallel, not truly closely related. This, I take it, is correctly interpreted by Ortmann as indicating an Asiatic center of dispersal for this genus. But in place of supposing with Ortmann that *Cambarus* originated from species of *Potamobius* pushing down southward into Mexico and thence northward again (as *Cambarus*) into the United States, it seems to me that the rational explanation would be to suppose that both genera are the disconnected remnants of a formerly Arctic center of dispersal. This would be first split in two by a progressively unfavorable environment, one division passing down into America east of the Cordilleras, and developing into *Cambarus*, the other part in Asia progressing more

slowly into *Potamobius* and spreading east and west from that center, as the American group spread southward.

DISTRIBUTION OF *HELIX HORTENSIS*

Dr. Scharff¹²² regards the distribution of *Helix hortensis* as an important part of the evidence in favor of a late Cenozoic bridge connecting Europe with eastern North America. The species is well known in Europe and has always been regarded as indigenous there. It occurs along the North Atlantic coast, and in Labrador, Greenland, Iceland and the Shetland and Faroë Islands. It was formerly considered as introduced on this side of the Atlantic by human agency; but it has been found in old Indian shell-mounds and more recently in undoubtedly Pleistocene deposits in Maine. It is unknown in Asia or western North America. Hence, Dr. Scharff concludes that it must have migrated from Europe to America across a land bridge via Iceland and Greenland in Pliocene or Pleistocene times.

The early opinion that *Helix hortensis* is an introduced species in this country was founded, so far as I recall, mainly upon the peculiar local range and habitat of the species, very different from the truly indigenous New England land-snails, and my early experiences in land-snail collecting in southern New Brunswick were quite in accord with this evidence. It is quite possible that *Helix hortensis*, like the genus *Equus*, is both introduced and indigenous.

Granting that it is at least partially indigenous, what evidence is there that the present distribution is not the remnant of a Tertiary circumpolar distribution? The fact that it is not recorded in the Tertiary of Asia? But what proportion of the presumably abundant Miocene or Pliocene land-snails of Asia is known to us? It can only be a minute fraction at the best—less than one per cent. So the chances are a hundred to one that if *Helix hortensis* or an ancestral form of the species existed in the Tertiary of North Asia, we should have no record of its existence at present. We do, however, have a good deal of indirect evidence that an environment favorable to the present habits of the species existed during the later Tertiary in the region intervening between its present discontinuous distribution areas, and that the environment became unfavorable in that intervening region at the close of the Tertiary. I can see no need for assuming a transatlantic land bridge to account for the distribution of this species. And the explanation here suggested is in harmony with the known course of distribution of those members of the northern

¹²² R. F. SCHARFF: Proc. Roy. Irish Acad., vol. xxviii, p. 19. 1909.

land faunæ whose past history is preserved to us in the geologic record. It involves only those minor changes of continental level (a few hundred feet) of whose occurrence during the Pleistocene we have ample evidence.

On the other hand, if we assume such a Transatlantic land bridge during the late Tertiary we must suppose an elevation of upwards of five thousand feet, a huge disturbance of the isostatic balance of whose possibility we have no real evidence; for the submerged channels so often cited in support of these immense uplifts have been shown by Chamberlin to be much more probably due to "continental creep," to the slipping down, so to speak, of marginal sediments to a lower level.¹²³ In any case, there could be no evidence as to the period at which these old channels were last above water. They may have been submerged since the Permian, for aught we know to the contrary. Furthermore, we have to explain the non-migration of a multitude of forms which got just so far as conservative land elevations could carry them, but no farther.

DISTRIBUTION OF PERCIDÆ

Another instance upon which Dr. Scharff lays great stress is the distribution of the perches. Here, the false impression produced by the use of a Mercator's projection map in plotting the distribution of northern forms, seems to me to be very obvious. This map does not give the northern regions in their true proportions or relations. Transferring the distribution of this family as plotted by Tate Regan, to a north polar projection map we get the real relations and proportions with approximate correctness. It then becomes obvious that the perches are centered around the drainage basin of the Arctic ocean. In North America they have extended down the Atlantic coast drainage area and into that of the Gulf of Mexico as far as the Rio Grande. In Asia they have been admitted by the old Hyrcanean Sea into the present Caspian and Aral basins; and a glance at the late Tertiary geography of Europe will show how they have reached the drainage basin of the northern Mediterranean. They are not now found in the Arctic drainage area of western North America, Greenland or Iceland, where the environment, now or in the Pleistocene, is amply sufficient to account for their extinction. What need of a transatlantic land bridge to account for this distribution.

¹²³ There is another possible explanation. The progressive building out seaward of barrier reefs around a number of separate centers until they joined into a platform would naturally leave deep intervening channels, especially off the mouths of great rivers where the influx of mud and fresh water hindered the growth of the coral organisms. The submarine contours around the West Indian islands especially suggest this explanation, which I offer tentatively for the consideration of my better-versed confrères.

A fourth instance cited by Dr. Scharff is the distribution of the river-mussel *Margaritana*, and as he well observes, numerous other instances would probably show similar discontinuous distribution. But, so far as I have been able to find such instances, the same reasoning and the same explanation apply to them all.

CRITICISM OF SOME OPPOSING HYPOTHESES

It is not practicable to take account here of the flood of paleogeographic discussions of recent years which have advocated all sorts of consistent or inconsistent changes in continental outlines. They agree for the most part in failing to take into account certain considerations which to my mind are essential elements in any problem of distribution.

Among the geological considerations are the following:

1) Evidence that the present distribution of the deep ocean basins is in the main due to isostatic balance. This affords a strong presumption in favor of its permanence.

2) Absence of abysmal deposits in the geological formations of any continental region. Chalk deposits are not an exception, as it has been shown that they were deposited in shallow epicontinental seas rather than in deep oceanic basins.

3) Abrupt ending of an elevated line of disturbance and its continuation as a submerged line of disturbance does not necessarily indicate that the submerged portion was formerly elevated, although it does reduce the improbability of its former elevation by indicating a line of disturbance and hence of possible elevation.

4) The presence of marine formations of Cretaceous or Tertiary age over large portions of the interior of the great continents does not indicate that these continents first came into existence as such during the Cretaceous or Tertiary. In the better known portions of the earth's surface we know well enough that these marine formations were due to periodic temporary submergence, interrupted by periods of more or less complete emergence. It is but reasonable to apply the same explanation to the less known regions. I see no more reason to suppose, as do Von Ihering, Scharff and others, that South America first came into existence as a united continent in the Tertiary, than to conclude on similar evidence that North America was but a group of isolated land masses until the end of the Cretaceous. In this country, we have positive proof of its antiquity; but the evidence for recent origin of the South American would apply just as well to the North American continent. A similar presumption of antiquity applies to Australia, Asia and Africa.

Among zoölogical considerations we may mention the following:

1) The discontinuous distribution of modern species is again and again taken as proof that the regions now inhabited must have been connected across deep oceanic basins, without considering the possibility that it is a remnant of a wider past distribution, or that it is due to parallel evolution from a more primitive type of intermediate distribution, now extinct. Yet so many instances are known where the geological record has furnished proof that one or other of these explanations applies to cases of discontinuous distribution, that it would seem that these ought to be the first solutions of the problem to be considered, and that in view of the known imperfection of the geologic record, mere negative evidence is not sufficient to cause them to be set aside.

2) No account is taken of faunal interchanges often much more extensive, which would presumably have taken place if the land bridges assumed had existed, but which have not taken place. It may here be urged that this too is negative evidence. But the negative evidence derived from an appeal to the geological record is weak, not *per se*, but because of the demonstrated imperfection of this record. On the other hand, there are many instances where a land bridge is well proven, and in these cases it is not a few scattered exceptions but an entire fauna that has migrated, subject only to the restrictions imposed by climatic or topographic barriers of other kinds.

I may venture upon a discussion of a few instances in order to show the type of objections which appear to me to apply to much of the evidence cited in favor of most of these transoceanic land bridges.

ON VAIN SPECULATIONS

According to some distinguished paleontologists,¹²⁴ progress is to be made only by ignoring the possibility that races have originated in or migrated from regions of whose former life we have substantially no record, and assuming that they must have evolved in one or another region where the record is more or less known, and that the actual record must be the sole basis for any conclusions. They refuse to consider the arguments for origin elsewhere, on the ground that such hypotheses are "vain speculations" and "serve merely to conceal our ignorance."

To this I may answer that a fair and full consideration of the data at hand shows that such hypotheses, of one kind or another, are absolutely necessary, unless we are to abandon all belief in the actuality of evolution and are to treat it as merely a convenient arrangement of successive spe-

¹²⁴ Depéret, Thévenin and others.

cies and faunas independently created. Such a view was held by Agassiz and most of his predecessors, but it is unnecessary to consider it in the present state of scientific belief.

If, on the other hand, we accept the belief that the successive species of each phylum are genetically related, how are we to explain the fact that these phyla are usually approximate and not direct, and that where the evidence is most complete, the fact that they are not in a direct line of structural evolution stands out most clearly. Take for example the ancestry of the horse, the most striking, easily recognizable, widely known and thoroughly studied illustration of mammalian evolution. It was possible, when the "documents" were few and imperfect, to trace a supposedly direct line of ancestry through European predecessors. Later, when the fossil fields of the western United States were first explored, a much more direct line of ancestry was found in this country, and the European series was recognized as not being the direct line. But the further progress of exploration in America, and the discovery of complete skeletons of the supposed ancestral stages known at first only from fragmentary specimens, has demonstrated that this line too is an indirect and approximate series so far as the succession of the known species is concerned. This has been recognized in recent years by American students, and variously phrased or interpreted. The most probable explanation of the facts is to suppose that the known phylum is approximate, not direct; that the direct line of descent leads through unknown or imperfectly known species, and that those known to us are offshoots of varying closeness. The direct line is, then, admittedly through hypothetical species, and the only question is whether the habitat of these species was in the regions where we have searched vainly for their remains, or in the much greater intervening region where we have not searched. Horses are found throughout the Tertiary in central and western Europe on the one hand, on the Western Plains of America on the other. There is every reason to believe that they inhabited all or parts of the intervening region and we have no right at all, in weighing the evidence, to refuse to take this region into consideration, on the plea that it has furnished no "documents" as yet. To place such limitations on our theories would hardly tend to solving our problems, however much it might seem to simplify them. It is merely to prefer a conclusion that we know to be false to a conclusion that we cannot prove by direct evidence to be true.

What I have stated in regard to the fossil ancestry of the horse applies to most mammalian phyla, in greater or less degree according to the perfection and number of our "documents." Where these are few and fragmentary, it is still possible to build up phyla which cannot be proven to

be inexact. But, as knowledge increases and becomes more exact, these phyla are more and more broken and complex, and direct genetic series become more limited in extent. This is to be expected, for the regions which up to date have been at all thoroughly explored are but a small fraction of the area which the group concerned must have inhabited. And on *à priori* grounds, the chances are greatly against the particular species which was to become dominant inhabiting the particular regions which we have explored.

Professor H. F. Osborn has very well expressed the conditions of evolutionary progress by stating that each group is highly polyphyletic, consisting of numerous subphyla evolving along more or less parallel lines. But we are here concerned less with the disentanglement of the subphyla of a group than with its dominant center of dispersal as a whole. And from this point of view it seems to me misleading and erroneous to assume that it must have migrated only from one to others of the regions where its remains have actually been found, instead of attempting to locate from the indirect evidence available the true center of dispersal.

In contrast with the views here criticized, I may venture to quote from an address in which Dr. Stehlin¹²⁵ has recently summarized the phylogenetic results of his monumental studies upon the Eocene fauna of Egerkingen, a work of extraordinary thoroughness and ability which, as a recent reviewer observed, has involved a revision of the entire Eocene mammal fauna of Europe: "Where then dwelt these yet unknown herds of mammals evolved during the Eocene, whose existence is recorded through their influence upon Europe and North America the more clearly as we analyze more closely the data obtained in these continents? We can scarcely be wrong if we look to the huge continental mass of Asia, still almost unexplored by the paleontologist. The future, and, it may be hoped, the near future will show how far our present anticipations are correct."

SUMMARY OF EVIDENCE

The geologic evidence for the general permanency of the abyssal oceans is overwhelmingly strong. The continental and oceanic areas are now maintained at their different levels chiefly through isostatic balance, and it is difficult to believe that they could formerly have been reversed to any extensive degree. The floor of the ocean differs notably in its relief from the surfaces of the continents, and only in a few limited areas is the relief suggestive of former elevation above sea-level. The continental shelf is

¹²⁵ H. G. STEHLIN: Verh. Schw. Naturf. Gesell., 93 Jahresversammlung, Sept. 1910. P. 29 of separata.

so marked, obvious and universal a feature of the earth's surface that it affords the strongest kind of evidence of the antiquity of the ocean basins and the limits beyond which the continents have not extended. The supposed evidence for greater elevation in the erosion channels across its margin have been shown to be better interpreted as due to "continental creep." The marine formations now found in continental areas have all been deposited in shallow seas. No abyssal deposits have ever been certainly recognized among the geologic formations of the continental platform.

Leaving out of consideration speculative hypotheses as to a formerly smaller amount of water on the surface of the globe, shallower ocean basins in Paleozoic times and different land and water distribution in the older geological periods, it is sufficient for the purposes of this discussion to emphasize the great weight of geological and physiographic evidence for the permanency of the continental masses as outlined by the continental shelf, during the later geological periods, and especially during the Tertiary.

The present distribution of continents and oceans on the surface of the globe (as outlined by the continental shelf) consists of a great irregular northern mass including Europe, Asia and North America, with three great partly isolated projections into equatorial and southern latitudes, South America, Africa and Australasia, and a smaller Antarctic land mass wholly isolated. The three peripheral continents are isolated from each other and from the Antarctic land by broad and deep oceans, but with the doubtful exception of Australasia, are united to the central mass by shallow water or restricted land connections.

A rise of 100 fathoms would unite all the continents and continental islands, except perhaps Australia, into a single mass, but would leave Antarctica, New Zealand, Madagascar, Cuba and many smaller islands separate. A further elevation of five times this amount would not alter materially the boundaries of land and sea. A submergence of 100 fathoms would isolate the three southern continents, and cause shallow seas to spread widely over the interior of all the continental masses, reducing some of them to isolated fragments or archipelagoes.

Such cyclic alternations of emergence and overflow are recognized by many geologists as the dominant feature of the earth's history, corresponding to the succession of periods into which geologic time is divided. The greater disturbances resulting in folding, faulting and mountain making, while involving much greater changes of level, affect more limited areas, adjacent to lines of unstable equilibrium, especially along the borders of the continental platforms.

Associated with these great cycles of elevation and submergence are climatic cycles from extremes of cold or arid zonal climates culminating in glacial epochs, to the extremes of warm humid uniform climates which accompany or follow the extremes of submergence.

The effect upon terrestrial life of progressive elevation of the land areas, accompanied by a progressively cold climate at the poles and arid climate in the interior of continents, would be to adapt the terrestrial life to cold, arid and highly variable climatic conditions. The environment favorable to this adaptation will appear first near the poles, and the northern and southern faunæ will be more progressive and will tend to disperse towards the equatorial regions. The wider area of emerged continents will tend to expansive evolution of the land faunæ, and their union into a single land mass will facilitate cosmopolitan distribution. Owing to the conformation of the continents the dispersal will be chiefly from the Holarctic region, the Antarctic and southern lands being unfavorably situated for the evolution and dispersal of dominant races and contributing but little to the cosmopolitan faunæ of the emergent phase. These conditions are also favorable to the development of higher, more active and more adaptable types of terrestrial life, which tend to supplant even in moist tropical regions the less adaptable remnants of the tropical faunæ which find there their last refuge.

During the opposite phase of the cycle, the faunæ become progressively readapted to the moist tropical climatic environment. But owing to the higher evolutionary stage acquired during the arid phase, the higher and dominant types of the new fauna are evolved chiefly by readaptation of the dominant types of the arid phase and only subordinately by expansive evolution of the tropical fauna surviving through that phase.

The paleontologic record appears to be in exact harmony with these principles, provided due allowance be made for its imperfections. The geographic distribution of animals and plants affords far more complete data, but their true significance has in my opinion been misinterpreted by many zoögeographers. When interpreted in harmony with the principles of dispersal shown to be true among mammals, they yield fully concordant results. The geologic record is to-day far more incomplete than is generally admitted, and will always be incomplete. Negative evidence, while sometimes of high value, is more often worthless and should never be admitted without a careful canvass of the situation in each instance.

The population of oceanic islands is notably incomplete and cannot be interpreted as due to continental connection. The difficulties in the way of over-sea transportation are best explained by the hypothesis of natural

rafts; the degree of probability that attaches to this hypothesis is estimated.

The dispersal of mammals is then considered at some length, order by order, and it is shown to accord fully and in detail with the principles here set forth, and to be impossible of explanation except upon the theory of permanence of the ocean basins during the Cenozoic era. While the prominence of the Holarctic region as a center of dispersal is ascribed to its central position and greater area, some evidence is given to show that climate is also a factor in the greater progressiveness of the northern, since it is also noticeable in the southern as compared with tropical faunæ.

The distribution of the Reptilia appears to be in conformity with the principles here outlined, and extends their application to the Mesozoic era. The distribution of birds and fishes and of invertebrates and plants is probably in accord with the same general principles, modified by differences in methods of dispersal. The opposing conclusions that have been drawn from the distribution of these groups are believed to be due to an incorrect interpretation of the evidence. A few instances, which have been prominently used to support opposing conclusions, are analyzed and shown to conform to the conclusions above set forth, if interpreted upon similar lines as the data for mammalian distribution.

APPENDIX

Since this paper was written two very readable and instructive books on geographic distribution have appeared, "The Wanderings of Animals" by Professor Gadow,¹²⁶ and "Distribution and Origin of Life in America" by Professor Scharff.¹²⁷ Both writers, and especially Doctor Scharff, belong to what may be called the bridge-building school of paleogeography, and the general criticisms expressed in the earlier part of this article apply largely to their interpretations. It is with no intent to depreciate their value that I observe that there are numerous errors of fact in those portions of the evidence with which I am best acquainted, for in a subject of so wide a scope most of the evidence is necessarily compiled and not very well understood, and errors more or less essential will slip in. It is for that reason that I have avoided detailed discussion of the parts of the evidence on the present subject with which I am not well acquainted; and, in spite of a good deal of checking and revision, I have no doubt that the foregoing discussion contains various inaccuracies.

¹²⁶ HANS GADOW: "The Wanderings of Animals." Cambridge Manuals of Science and Literature, No. 64. 1913.

¹²⁷ R. F. SCHARFF: Distribution and Origin of Life in America. Macmillan Co., publishers, New York. 1912.

A more serious criticism is the illegitimate and often partisan use made of negative evidence. This is doubtless due to the same cause, a mere book knowledge of the fossil record, and failure to examine and weigh its evidence. But it is very obviously affected by a readiness to rely on negative evidence that favors their theories and to ignore a vastly greater amount of negative evidence that does not.

Dr. Gadow considers it "awkward" for the theory of Holarctic dispersal of the marsupials in the Cretaceous that no survivors have been recorded in the Tertiary of Asia. He prefers to believe that the Australian marsupials arrived via Antarctica from South America. If it is "awkward" for the one theory, that although survivors are found in the early Tertiary of both Europe and North America, none have been found in Asia, then it must be equally "awkward" for the theory that Dr. Gadow supports that none have been found in Antarctica. For we know even less about the early Tertiary of Asia than we do about the Antarctic Tertiary. If the absence of zalambdodont insectivores in the Eocene of Europe is to be assigned any weight, then equal weight should be assigned to their absence from the Oligocene and Eocene of South America and from the Pleistocene of Cuba, of Madagascar and South Africa. We know as much about the one fauna as we do about the others. The negative evidence has no weight in any of these instances; *per contra*, the fact that zalambdodonts are known to have lived in the early Tertiary of North America (Paleocene to Oligocene) affords a presumption of their presence in the nearly allied early Tertiary faunas of Europe, just as their presence in the recent faunas of Madagascar and South Africa and in the Miocene of South America affords a presumption of their presence in the nearly allied faunas which immediately preceded them. Equally, the presence of marsupials in the early Tertiary of Europe on one side of Holarctica and of North America on the other side raises a strong presumption of their presence in the intervening region of Asia from which no fossils are known. They are not found in the later Tertiary of Europe and America, so that we should not expect to find them in the later Tertiary of Asia. On the contrary, the small fragment of evidence that we have as to the Tertiary fauna of Antarctica affords a slight presumption against the presence of mammals on that continent.

Doctor Gadow's statement that the Chiroptera did not reach America until the Pleistocene is another curious instance of the misuse of the fossil record, which no one familiar with the character of our Tertiary formations and the necessary limits of the fossil faunas would be likely to make; nor would anyone acquainted with the variety and specialization of the New World genera be inclined to believe that it was all the

result of post-Pliocene immigration and differentiation. Most of the creodonts, he informs us, "died out with the Eocene or rather they were modernized into the typical Carnivora in various parts of the world. Some, however, kept on to almost recent times as highly specialized creodonts, *e. g.* the sabre-toothed tigers: *Nimravus* in North American Oligocene; *Machærodus* from Miocene to Pleistocene in Europe and Asia, whence in the Pleistocene it appeared as *Smilodon* in America.

. . ."¹²⁸ It is perhaps unnecessary to point out that the machærodonts were not creodonts but typical Carnivora of the family Felidæ, and that their evolutionary series is fully as complete and progressive in the Nearctic as in the Palæarctic record. I may also note that "small swine" (meaning I suppose the primitive bunodont artiodactyles from which both pigs and peccaries are derived) appeared in North America quite as early as in Europe; that the genera *Procamelus* and *Pliauchenia* do not mark the splitting of the Camelidæ into camels proper and llamas; that *Dorcatherium* is not identical with "*Hyomoschus*" (*Hyæmoschus*) and is an older name; that *Arsinoitherium* is not a pair-horned dicerathere but is a representative of a distinct order of mammals; that the precise relations of the American Eocene tapirs have yet to be determined; that *Protapirus* does not first appear in the Lower Oligocene of Europe but in the Mid-Oligocene of Europe and North America; that there is no reason to believe that the European *Paratapirus* is more directly in line of descent of the later tapirs than is the so-called *Tapiravus* of the American Miocene, and that the very fragmentary and inadequately studied record of the evolution of the Tapiridæ is quite inadequate for the positive and exact statements which Gadow makes as to their "wanderings."

The statements as to the evolution of the horse show a surprising amount of inaccuracy, considering that this is so widely known a story. Apparently, it is in part the result of an attempt to criticize and modify the conclusions of American writers on the basis of a hasty survey of the incomplete materials available in European museums. The Eocene ancestors are disregarded, because they "are still so very generalized that they lead to horses, rhinos and tapirs as well as to other distinct groups." While this is not far from the fact as regards the Lower Eocene *Eohippus*, it certainly is not true of *Orohippus* and *Epihippus* of the Middle and Upper Eocene. The relations of *Miohippus* to *Mesohippus* are hardly to be dismissed with a "perhaps." *Desmatippus* is not an ancestor of *Parahippus* but is identical; *Hypohippus* is not intermediate between *Para-* and *Merychippus* but is an aberrant type descended from *Miohippus*

¹²⁸ *Op. cit.*

through *Anchitherium*; the American Miocene series does not come to an end with *Merychippus*, but this genus gives rise through numerous intermediate species to *Protohippus*, *Pliohippus* and *Hipparion*. *Hippidion* is not a descendant of *Hipparion* but of *Pliohippus*. There is, it is true, a considerable gap between *Hipparion gracile* and *Equus*, this species being too specialized in tooth pattern and its lateral digits exceptionally heavy; but most of the American hipparions are simpler and less aberrant in tooth pattern and the shafts of their lateral digits reduced often to mere threads. The proximal splints in these forms are very nearly as much reduced as they are in *Equus*; the gap which Doctor Gadow declares has been "slurred over" lies simply in the fact that no specimens have yet been found in which the shafts of the lateral digits are discontinuous but the distal rudiments preserved. Anyone familiar with the difficulty of securing proof of this condition in a fossil species, and with the imperfection of our record of the Pliocene Equidæ, will hardly consider this as a serious gap. Certainly, it is trifling in comparison with the gaps in any of the other mammalian phyla which Doctor Gadow accepts without difficulty. As for the derivation of *Equus* from primitive species of *Hipparion* rather than of *Protohippus*, my opinion to that effect rests upon intensive studies of Miocene Equidæ undertaken for Professor Osborn's monograph of the Evolution of the Horse (in preparation) and I do not think it fitting to publish the evidence in its support at present.

The sirenians, Dr. Gadow tells us, afford strong support of the theory of a transatlantic bridge, the earliest being known from the Eocene of Jamaica and Egypt, etc. They would, undoubtedly, if there were sufficient reason to believe that they were absent from the more northerly parts of the North-Atlantic-Arctic shores during the early Tertiary. But there is none whatsoever; the North Atlantic coasts either extended during the Tertiary beyond their present limits to or towards the continental shelf, or else their marine and littoral deposits have been destroyed by glaciation; at all events none remain above water worth mentioning from New Jersey on one side around to the British Isles on the other. That no littoral vertebrates should be known where there are no littoral deposits is not surprising; yet it is upon this worthless negative evidence that the "strong support" rests.

I have limited myself in the foregoing criticism to noting a few points in regard to fossil mammals. Dr. Scharff's book is far too extensive for any detailed criticism here, even within these limits. I can note only that, while highly instructive as well as entertaining, it is far from being either accurate or fair in its treatment of the geological aspects of the

subject or the fossil record. The view that during the Glacial Epoch the glaciers were confined in this country to the higher mountain ranges¹²⁹ is one that even a biologist is hardly excusable for upholding. Nor does it seem that anyone discussing the Tertiary geography of North America should be so little informed as to suppose¹³⁰ that the eastern and western portions of the continent were separated during the Eocene by an ocean barrier. In his argument against the permanency of the ocean basins, Scharff is, on the other hand, able to quote high authority. But the weakness of the argument is nevertheless apparent. That there have been great changes of level along certain lines of disturbance has never been questioned. But the conclusion that the continental platforms have never been submerged to abyssal depths, based upon the entire lack of abyssal deposits in their geological succession, is not disproved but rather confirmed by the recognition of abyssal deposits on an oceanic island lying along a line of high disturbance. For that merely proves that abyssal deposits are recognizable as such when they do occur, absence from the continental platforms remains untouched. Nor does the occurrence of ancient sedimentary and metamorphic rocks on some, especially of the larger, oceanic islands afford any evidence that they are remnants of former continents. The same processes of sedimentation, regional metamorphism and orogenic upheaval must of necessity occur in any oceanic island of considerable size and antiquity, and produce similar results both stratigraphic and petrographic. Moreover, if such islands lie in a line of disturbance which is continued under the ocean to an adjacent continent the same earth-movements may well affect both areas without raising the intervening region above the abyssal depths in which it now lies.

Dr. Scharff adopts Ameghino's correlations of Argentine formations, and Von Ihering's assertion that the continent of South America did not exist as a single land mass until late in the Tertiary. I may note by the way that Ortmann¹³¹ not long ago, in reviewing Pfeffer's¹³² essay on the zoögeographical relations of South America, rebuked him severely for not being aware of this "undoubted fact," which he declared was not a theory at all. The real facts are that marine and fresh-water formations of Jurassic, Cretaceous and early Tertiary age occur extensively in the interior of South America, indicating that the broad low-lying interior of that continent was periodically flooded by shallow seas. The conditions parallel those of the North American continent very closely,

¹²⁹ *Op. cit.*, pp. 46 ff.

¹³⁰ *Ibid.*, p. 357.

¹³¹ A. E. ORTMANN: *Amer. Nat.*, vol. xxxix, pp. 413-416. 1905.

¹³² G. PFEFFER: *Zoöl. Jahrb.*, Suppl. 8, pp. 407-442. 1905.

so far as they are known. The North American continent we know existed as such throughout geological time, although extensively flooded at times by shallow seas, especially during the Middle Cretaceous. The same is presumably true of South America.

Like Doctor Gadow, Doctor Scharff makes a wholly unjustifiable use of negative evidence where it may serve to support his views. He is a much more reckless bridge-builder, and appears to be quite unconscious of any difference in probability between such a bridge as the Alaska-Siberia connection and the various trans-Atlantic and trans-Pacific bridges which he invokes. Yet the Alaskan bridge is in existence to-day, only a few yards of its planking removed, if one may so speak, the substructure intact, and the marks of the missing planks still showing on the undamaged portion, while the huge bridges which he "prefers" to believe in are, except for the Icelandic ridge, scarcely indicated by so much as a sandbank on the flat abyssal floor of the vast intervening oceans. That he can claim support of a kind from so high an authority as Suess may be true, but scientific problems should be settled by examination of the evidence, not by citations of opinion from selected authorities.

Doctor Scharff does not at all believe in accidental transportation by floating vegetation or other natural means. Why, he demands, do not the advocates of such views cite instances of such transportation in modern times, and why is it only the more ancient animals that are so transported? The argument is curiously parallel to the favorite anti-evolutionist demand. Why, if man has evolved from a monkey, do not the scientists take a monkey and turn him into a man? Of course, the proof demanded is an impossibility. If any instances of such transportation were noted during the last few centuries, they would be ascribed to human agency; but the probabilities within that time are slight except in islands near the coast, such as Krakatau; for more distant islands they are made probable only by the vast length of geological periods, and it is a matter of course that the more ancient the type, the longer time and consequently better chance there has been for its transportation by accidental agencies.

Like all authors who advocate union of the Galapagos islands with the mainland, Dr. Scharff does not distinguish between a union of the islands with each other, which is geologically probable and is an almost unavoidable conclusion from a study of the fauna, and their union with the mainland, which is highly improbable on geological and physiographical grounds, and is not merely unnecessary to explain the fauna but impossible to reconcile with its peculiarities by any reasonable theories which take into account all of the consequences of such union.

While Doctor Scharff's interpretation of the data is based upon fundamentally different principles above noted, and his statements as to fossil distribution are often inaccurate or incomplete, yet the numerous distributional data which he presents of modern invertebrates are of great interest, and, if interpreted along the lines which I have used, they fall completely into line with the vertebrate evidence. We cannot usually indeed check the conclusions drawn from modern distributional relationships by the fossil record. Many groups are altogether unknown, and the record in others is very scanty, but the same general relations clearly apply. The survival in Western Europe on one side, in southeastern North America on the other side, of a somewhat primitive cycle of Holarctic distribution; the survival in the Mediterranean region on one side, in Central America and the Antilles on the other, of a more primitive cycle; of a still more primitive cycle in Africa and South America; and the progressively greater amount of divergent or parallel specialization in the survivors of the earlier cycles; the antique and fragmentary character of the faunæ of the oceanic islands, progressively more so in proportion to their smallness and isolation—all these conform to the vertebrate distribution. And with invertebrates as with vertebrates, every year adds to the number of the types which, while now limited to the peripheral continents and oceanic islands and highly discontinuous in their range, are shown to have inhabited formerly the central Holarctic region. It appears that many, one might perhaps say most, invertebrates are more readily transported across ocean barriers than vertebrates, especially mammals, even making due allowance for their greater antiquity. This also we should expect.

I do not think it necessary to catalogue the errors or inaccuracies in presenting the evidence afforded by fossil vertebrates. Such errors are unavoidable in a subject of so broad a scope, and excusable enough, if they do not lean too much to one side. I shall cite but one instance, and this in justice to my distinguished confrère Professor Depéret. Doctor Scharff concludes his summary of the North American records of the Evolution of the Horse with the following remarks:¹³³ "And yet not a single transition from one genus to the other seems to be known. No wonder that one of our foremost paleontologists exclaims, 'The supposed pedigree of the horse is a deceitful delusion, which simply gives us the general process by which the tridactyl foot of an ungulate can be transformed in various groups into a monodactyl foot in view of an adaptation for speed, but this in no way enlightens us on the paleontological origin of the horse.'" Such a statement, coming from so excellent

¹³³ *Op. cit.*, p. 147.

an authority, seems startling until one verifies the quotation and finds that it refers, not to the American records, but to the ancestry of the horse as presented in Gaudry's¹³⁴ *Enchainements*, to the European series *Palæotherium*, *Anchitherium*, *Hipparion gracile* and *Equus*. Depéret takes care to premise that he is speaking only of this European series, and while I think the criticism goes too far—it should at least be modified by changing “ungulate” to “perissodactyl” in view of what we know about the Litopterna—yet the criticism is largely justified in its proper context. As applied to the American series it is altogether unwarranted.

¹³⁴ A. GAUDRY: *Enchainements du Monde Animal*, vol. III, *Mammifères tertiaires*. 1878.

DEVELOPMENT OF THE NEURAXIS IN THE DOMESTIC CAT
TO THE STAGE OF TWENTY-ONE SOMITES ¹

BY H. VON W. SCHULTE AND FREDERICK TILNEY

CONTENTS

	Page
Introduction.....	319
Description of embryos.....	321
Embryos prior to the appearance of intersomitic clefts.....	321
Embryos of one somite.....	321
Embryos of two somites.....	321
Embryo of three somites.....	322
Embryo of four somites.....	322
Embryos of seven somites.....	323
Embryos of eight somites.....	324
Embryo of nine somites.....	324
Embryos of ten somites.....	326
Embryos of twelve and thirteen somites.....	327
Embryos of fourteen somites.....	327
Embryo of sixteen somites.....	329
Embryo of seventeen somites.....	329
Embryo of nineteen somites.....	330
Embryo of twenty-one somites.....	331
Ganglionic crest.....	332
Closure of the Neural Tube.....	336
Prosencephalon.....	338
Mesencephalon.....	342
Rhombencephalon.....	344

INTRODUCTION

The present paper is a study of the morphogenesis of the neuraxis in its early stages, with especial reference to an attempted interpretation of the forebrain in terms of the longitudinal zones of the neural tube, viz., the basal and alar laminae, and the ganglionic crest. The theoretical problem can be stated briefly. Since the ganglionic elements are included in the wall of the neural tube at the time of its separation from the ectoderm—Neumayer has shown this for reptiles, and it is also true

¹ Presented in abstract by the senior author at the meeting of 11 May, 1914, under the title "Early Stages in the Development of the Brain in the Domestic Cat."
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of the cat—it is possible that in regions in which a ganglionic crest is not formed, homodynamous elements remain incorporated and form permanent constituents of the brain-wall. It ought not to be inferred, from absence of a discrete ganglionic crest in any region, that its equivalent is lacking, for it may simply have failed to separate from the neuraxis. On the other hand, with regard to the interpretation of the forebrain in terms of transverse segmentation, neuromeres, it would seem that a complete dorso-ventral segment of the neural tube should contain ganglionic, alar and basal elements, and that failing any of these it is something less and other than what the term neuromere properly implies. Now we have no evidence of the existence of the basal lamina in advance of the nucleus of origin of the oculo-motorius, nor can we see the advantage of assuming its presence in front of the point at which evidence of its existence ceases. Further, the transverse segmentation of the neuraxis is either the result of intrinsic factors, or what seems more probable, is at least in part secondary to the segmentation of the mesoderm. This is myomeric in the trunk, branchiomic in the head. That a secondary segmentation of the neuraxis thus effected should result in a continuous series of meristic equivalents seems on the face of it somewhat improbable. These, in brief, are the questions we have had chiefly in mind in attempting an ontogenetic analysis of the forebrain of the cat. At the same time it seemed desirable to record the general data concerning the neuraxis in a close and fairly numerous series of young embryos, for as yet the knowledge of these stages in mammals is far from extensive.

The list of embryos is as follows:

Prior to the appearance of somites.....	Nos. 339, 400, 456, 550, 555
One pair of mesodermic somites.....	Nos. 554, 594
Two pairs of mesodermic somites.....	No. 539
Three pairs of mesodermic somites.....	No. 593
Four pairs of mesodermic somites.....	No. 409
Seven pairs of mesodermic somites.....	Nos. 587, 588
Eight pairs of mesodermic somites.....	Nos. 530, 586
Nine pairs of mesodermic somites.....	No. 531
Ten pairs of mesodermic somites.....	Nos. 476, 532
Twelve pairs of mesodermic somites.....	Nos. 534, 547
Thirteen pairs of mesodermic somites.....	No. 86
Fourteen pairs of mesodermic somites.....	Nos. 188, 548
Sixteen pairs of mesodermic somites.....	No. 551
Seventeen pairs of mesodermic somites.....	No. 568
Nineteen pairs of mesodermic somites.....	No. 502
Twenty-one pairs of mesodermic somites.....	No. 558

The embryos were cut into transverse sections and reconstructed by the Born method at a magnification of two hundred diameters. Casts

of the lumina, as well as models of the neural tube, were made in each case and were found useful in controlling and interpreting the surface relief. The period of development of the neuraxis covered by these embryos extends from the appearance of the medullary plate to the definition of the pallial anlage. It will be convenient, first, to record the conditions observed in the several embryos and then proceed to a consideration of the morphological questions outlined above.

DESCRIPTION OF EMBRYOS

Embryos Prior to the Appearance of Intersomitic Clefts.—(Plate XXII, Fig. 1.) Toward the end of this period when the axial mesoderm has thickened and is on the point of becoming segmented, the medullary plate (5)² is represented by an oval thickening of the ectoderm which peripherally passes into the somatic ectoderm (7) by a gradual transition (28) without clearly defined limits. In some of our embryos there were irregular depressions and elevations of the surface, especially in its lateral regions, which presented some resemblance to the *Seitenfurche*, *Randfurche* and *Parietalzone* of authors, but which, in view of the uniform outlines of the excellent embryo here figured, we have not been able to convince ourselves were natural structures.

Embryos of One Somite.—(Plate XXII, Fig. 2.) In these embryos one pair of complete intersomitic clefts is present. In addition, the axial mesoderm presents on each side two or three transverse constrictions which are evidently due to the inception of somites. In the cat it appears that several somitic constrictions are initiated simultaneously. In our reckoning we have regarded only the complete clefts and the number of somites assigned to the embryos of our series are estimated in terms of complete clefts. In the two embryos which we have classed as having one pair of somites there are, in addition, two or three pairs of constrictions, one pair of which is situated in front of the first complete intersomitic cleft. The medullary plate (5) merges laterally into the somatic ectoderm (7) by a gradual transition (28) as in the earlier stages. Cephalad its axial region is depressed. We would call attention to the fact that the summits of these incipient medullary folds correspond to the middle zone of the medullary plate on each side.

Embryos of Two Somites.—(Plate XXIII, Fig. 1.) The medullary plate has the same general characters as in the preceding embryos. It is very broad and passes by gradual transition (28) into the somatic ectoderm (7) at the sides. Craniad the medullary groove is somewhat

²The numerals in italics refer to the numbers of the leaders in the figures.

deeper and the medullary folds have partially erected themselves over a greater longitudinal distance. Craniad also a faintly marked furrow is present in the region where the medullary plate becomes thinner as the somatic ectoderm is approached. In addition, the lateral region of the plate presents slight undulations of the surface.

Embryo of Three Somites.—(Plate XXIII, Fig. 2.) The neuraxis has the same general configuration as in the preceding embryos. The boundary between the medullary plate (5) and the somatic ectoderm (7) is still effected by a gradual transition (28). Craniad there is a faint furrow as in the embryo of two somites, and in this region also the margin is marked by faint undulations.

Embryo of Four Somites.—(Plate XXVII, Fig. 1; Plates XXIV-XXVI.) The neuraxis has not lengthened appreciably as compared with the embryos of three and of two somites. In its cranial half, however, the neural folds (5) have fully erected themselves and an abrupt boundary has been established between them and the somatic ectoderm (7). Caudad this junction is still effected by a gradual transition; there is no furrow. The floor plate terminates craniad in a distinct thickening and elevation (2) which intervenes between the ventral extremities of the optic sulci (1). In front of them it is continuous with the ectal margins of the primitive optic vesicles. We have designated this elevation the tubercle of the floor. The optic sulci begin on each side of the tubercle of the floor where they are continuous with the angle that defines the floor-plate from the parieties. They describe an arc with the concavity caudad and approximately parallel to the margin of the neural plate, but approaching the neurosomatic junction and becoming fainter as they are followed caudad. Corresponding to their arched segment there is a marked thickening and external prominence of the wall of the neural tube.

At a short distance caudad to the optic sulci there are a pair of similar though shallower furrows, close to the neurosomatic junction. Their course is at first horizontal; their caudal portions turn ventrad and approach but do not reach the floor-plate. Corresponding to their horizontal portion, there is a ridge-like projection between the summit of the neural plate and the somatic ectoderm. This ridge is the quintal anlage (3). That it is more intimately related to the neural fold (5) than to the somatic ectoderm (7) is shown both by the fact that the neurosomatic junction is dorsal to it and by the fact that it blends at both of its extremities with the thickened dorsum of the neural plate. It is in no sense an element intermediate between neural plate and ectoderm. Just behind the quintal anlage is another, smaller furrow

(4) which is not accompanied by any definite local protrusion of the wall but simply grooves the medullary fold entally near the neurosomatic junction, becoming broad and shallow and disappearing before the floor-plate is reached. This furrow corresponds to the acoustico-facial anlage in older embryos. We would note further that on the right side there is a small pit situated midway between the optic and quintal sulci having the same characters as the latter, except that it is unaccompanied by an external protuberance and is present only in three sections of 13.3 micra each. This had no homologue on the left side. It is possible that this minute furrow represents the profundus anlage, although clear evidence of its presence is not found in our embryos until the stage of twelve somites is reached. A similar conformation was observed farther caudad on the left side in the region behind the last somite; it extended over three sections. Caudad the medullary folds divaricate and become lower, eventually disappearing in the region of the primitive groove. In contrast to the cranial extremity, it is to be noted that here the first portion elevated is the lateral and not the basal zone of the medullary plate. This is characteristic of this region in later stages as well. It is apparent, therefore, that, both craniad and caudad, the elevation of the neural folds is accomplished in two phases but that the order of events is reversed at the two ends of the embryo. Craniad the basal region first becomes vertical, then the lateral, while caudad the converse is true. This is the only evidence we have been able to find of a morphologic difference between the basal and alar plates, for the sulcus limitans is a late formation, if it is present at all in young embryos of the cat.

Embryos of Seven Somites.—The neural folds are separate in their entire length and in general show but little advance in comparison with the embryo of four somites. The optic sulci are strongly arched and the prominence of the primitive optic vesicles is slightly increased. The tubercle of the floor intervening between the two optic sulci forms a well defined cranial limit to the floor of the neural tube, and blending with the wall in front of the optic sulci forms the ventral lip of the neuropore. The quintal and acoustico-facial sulci consist of horizontal and obliquely descending segments, the latter in each case becoming broader and shallower as they approach the floor-plate. On the ectal surface of the neural plate faintly marked oblique elevations correspond to the oblique portions of these sulci. The quintal anlage forms an elongated ridge, extending a little farther craniad than the horizontal segment of the quintal sulcus. Its extremities now project free of the medullary plate, no longer fusing with it as in the embryo of four somites. This anlage enters into intimate relations with the mesenchyme of the head, the two tissues passing

into one another by such gradations that it is difficult and in some sections impossible to determine the precise limits of the ganglion.

Embryos of Eight Somites.—(Plate XXVII, Figs. 2, 3; Plates XXVIII-XXX.) While the neuraxis shows little if any increase of length in comparison with the preceding embryos, the closure of the neural folds has been initiated. This is first effected in the region immediately in front of the quintal anlage (3), where the folds obtain their greatest height (embryo No. 586). In embryo No. 530 there is an additional point of closure immediately caudal to the quintal anlage.

The optic sulci (1) have increased in depth and the optic vesicles form prominent, ellipsoidal projections with nearly vertical axes. Evidently they correspond to the arched segments of the optic sulci in the younger embryos; the horizontal caudal continuations of these furrows are now reduced. Caudal to the optic vesicle the wall of the neural tube is flat until near the quintal anlage (3), where a moderate dilation is present. This ganglion has now a triangular form and is shorter than in the preceding embryos. It is attached to the dorsum of the medullary plate near its junction with the somatic ectoderm, corresponding to the interval between the two points of closure of the neural tube (embryo No. 530) and at the summit of a slight constriction intervening between two moderate dilatations. The first of these dilatations (31) has already been mentioned; the second (12) corresponds to the oblique descending portion of the quintal sulcus, which as a whole in these embryos is undergoing reduction. The acoustico-facial ganglion (4) is small and has a shallow corresponding sulcus. The ganglion occupies the summit of a constriction immediately behind the quintal dilatation and is followed by a slighter enlargement (13) of the tube, into which its sulcus merges. It is then, in its sulcus and following dilatation, a repetition on a smaller scale of the quintal anlage. The common ganglionic crest extends from the acoustico-facial ganglion, with which it is continuous to the level of the fourth pair of mesodermic segments. In the caudal half of the neuraxis the neural folds are lower; at first parallel, they diverge in the region of the rhomboid fossa (21). Here the neural plate of each side comprises a horizontal mesial region, and a smaller lateral erected portion, the two meeting at a rounded angle. In the midline there is a vestige of the primitive groove (6).

Embryo of Nine Somites.—(Plate XXXI.) The closure of the neural tube is advancing rapidly. It is not, however, effected by a uniform advance in both directions from the region of earliest closure, but on the contrary is incident at several separate points of the neuraxis, as was foreshadowed in the eight-somite embryo. In addition to the anterior neuro-

pore (8), there are three small gaps (9) in the region of the quintal anlage (3) corresponding to the hiatus there present in the embryo of eight somites. Another small orifice (10) is situated in the region of the acoustico-facial anlage (4). Caudal to this the folds unite for a considerable distance but again separate (11) in the region of the fourth to the eighth somite; opposite the ninth they are again united for a short distance when they finally separate and diverge.

The anterior neuropore is markedly diminished in extent. That this is caused by closure at its ventral as well as at its dorsal lip is shown by a comparison of the models in Plate XXVII, Fig. 3, and Plate XXXI, Fig. 2. In the eight-somite embryo the optic vesicle is open in its whole extent; in that of nine somites closure has been effected in about half of its length. The prosencephalon shows a distinct advance beyond that of the eight-somite embryos both in size and in the complexity of its surface relief. It projects strongly ventrad, its caudal margin forming approximately a right angle with the floor of the neural tube. It is demarcated from the midbrain by a shallow anterior isthmian sulcus (22) which is very obliquely inclined. The optic vesicles form its ventro-cranial region; they are somewhat pyriform with a pointed caudal extremity and their long axes are inclined at an acute angle with the horizontal. Dorsally the optic vesicle is defined by a shallow depression; between this and the anterior isthmian sulcus are two small elevations, one on the dorsal and one on the ventral aspect of the tube. The dorsal eminence is the thalamencephalon (Plate XXXI, Fig. 2, 16) and is opened in its whole length by the neuropore. It is somewhat triangular in shape and its prominence diminishes ventrad where it is separated by a faint depression from the ventral eminence. This latter also has a triangular shape and is the first indication, in our series, of the mammillary region (Plate XXXI, Fig. 2, 17). Ventrally it is separated from the pointed extremity of the optic vesicles by a slight incisure which corresponds to a thickening and an inward projection of the floor-plate. As this is interposed between the ventral extremities of the optic sulci, it is evidently the tubercle of the floor (Plate XXXIX, Plate XL, Fig. 1, 2) of the earlier stages. The depressions defining the thalamencephalon and the mammillary region form an H-shaped system of furrows, while the two elevations taken together form a segment which separates the primitive optic vesicles from the midbrain. That this segment is not a neuromere in any precise sense of the term is obvious from its developmental history, for the two eminences of which it is composed fuse only at a considerably later period (sixteen somites). The prosencephalon lies immediately in front of the foregut and the entoderm is closely applied to the mammillary region. A com-

parison with the embryos of eight somites makes it evident that these changes are not wholly to be attributed to inequalities of growth, but that a profound remodeling of the cranial extremity of the neuraxis has taken place in addition, as is shown by the alteration in the direction of the optic axes, the inclination of the anterior isthmian sulcus and in the notable lengthening of the midbrain taken in connection with its diminished height.

Embryos of Ten Somites.—(Plate XXXII.) The union of the neural folds has progressed. The anterior neuropore (8) extends through the greater part of the length of the optic vesicles into the thalamencephalon (16), the somatic ectoderm being further adherent as far as the mesencephalon (15). In this segment of the brain and for a considerable distance caudad the folds have closed and the neural tube has separated from the ectoderm. The roof-plate is concave and depends into the lumen as a longitudinal ridge. Somewhat in front of the middle of the neuraxis there is a considerable hiatus in the line of closure of the neural folds and behind this are three small areas in which the ectoderm is still adherent, though closure has been completed (11). The fossa rhomboidalis (21) falls into two portions of about equal length. Cephalad it is narrow and the neural folds are high, approximated and nearly parallel. The caudal region is broad and bounded by low folds erected only in their lateral parts; here the neural plate still passes into the somatic ectoderm by a gradual transition.

The prosencephalon joins the rest of the neuraxis at an acute angle. The anterior isthmian sulcus (22) is horizontal with ventral concavity. The mammillary region (17) is well marked, as is also the thalamencephalon (16); the axis of the optic vesicle is horizontal. A posterior isthmian sulcus (23) defines the midbrain caudally. In embryo No. 476 this vesicle is obscurely divided into two segments by a shallow furrow. The hindbrain has three recognizable segments; the first (31) is triangular with its base ventral; the second (12) and third (13) are obliquely inclined and defined by shallow, oblique furrows. The quintal anlage (3) is attached in the interval between the second and third segments and the profundus anlage between the second and first (Plate XXXII, Fig. 2, 3a). This is the youngest embryo of our series in which the profundus element can definitely be made out. The acoustico-facial anlage (4) is separated by a short interval from the quintal anlage; it occupies the furrow which defines the third hindbrain segment caudally and is continuous with the ganglionic crest of the trunk (not shown in the model).

A second embryo of ten somites (No. 532) corresponds closely to the embryo just described, except for a somewhat greater degree of union of

the medullary folds. The anterior neuropore is reduced to a minute orifice situated ventrally at about the middle of the optic vesicles, thus affording, in comparison with the foregoing embryo conclusive evidence of progressive closure at the anterior lip of the neuropore and to this degree depriving the orifice of value in determining the morphologic cephalic extremity of the neural tube. Apart from this small opening the anterior neuropore is closed, but the ectoderm is adherent over the cranial portion of the optic vesicles and the adjacent region of the thalamencephalon. The midbrain shows no sign of division into two segments.

Embryos of Twelve and Thirteen Somites.—(Plate XXXIII.) These embryos form a closely graded series, passing from the conditions described in the embryos of ten somites to those attained by the fourteen somite embryos of our series. In the region of the anterior neuropore (8) they show a considerable degree of variation in the closure. In embryo No. 534 of twelve somites, the neuropore has been completely closed. The ectoderm is, however, adherent at the middle of the sagittal length of the optic vesicles and further over the region of junction of optic vesicle (1) and thalamencephalon (16). In embryo No. 86 of thirteen somites, the ectoderm is adherent in the whole length of the optic vesicle and there are three small orifices, one at the middle of the optic vesicle, one at its junction with the thalamencephalon and one in the thalamencephalon itself.

There are three oblique segments in the hindbrain; their intersegmental constrictions give attachment to the profundus (3a), quintal (3) and acoustico-facial (4) ganglia in the order named cranio-caudad. The acoustico-facial is continuous with the ganglionic crest (20) which extends for somewhat more than half the length of the neuraxis. Following these oblique ganglionic segments is a series of vertical segments; their constrictions corresponding to the mesodermic somites are six to seven in number. It is thus seen that the vertical segments of the neuraxis correspond in location to the somites, but lag considerably behind them in number, which we take to mean that an interval in time elapses between the formation of the mesodermic somite and formation of the corresponding myelomere. It seems to us, therefore, that ontogenetically myelomeres are secondary to the mesodermic somites. The three oblique hindbrain segments, associated with the three large ganglia, are situated in advance of the somites. We would emphasize the difference in their disposition as evincing their independence of the myomeric segmentation.

Embryos of Fourteen Somites.—(Plate XXXIV.) The two embryos of this stage in our series show a close correspondence in the neuraxis, save only that embryo No. 548 is in most respects slightly in advance of

its fellow, No. 188. The neural folds are united, except in the short, narrow rhomboid fossa, in the caudal portion of which the neural plate still passes by a gradual transition into the somatic ectoderm. The anterior neuropore (8) has closed, but the ectoderm is still adherent from the middle of the optic vesicle to the thalamencephalon. Embryo No. 188 is more advanced in this respect, for the ectoderm is free of the neuraxis in the whole length of the prosencephalon. It is, however, adherent in the midline from the level of the profundus anlage to that of the acoustico-facial ganglion. A comparison of these two embryos affords a striking example of the irregularity incident to the whole process of closure of the neural tube and its separation from the ectoderm in the cat, and seems to justify the attachment of less importance than is usually ascribed to the point of ultimate closure. The neuraxis is bent ventrad at the posterior isthmian sulcus (23). This is the second actual flexure observed in our series, for a comparison with the figures of the preceding embryos shows that the earlier projection ventrad of the prosencephalon was associated with a remodeling of the midbrain and an inclination of the anterior isthmian sulcus, while in the stage now under discussion the bend is accentuated at the posterior isthmus. The hindbrain forms a gentle arch passing into the straight myelencephalon. In the forebrain important new conditions are initiated. The optic vesicle (1) is now not only relatively but absolutely smaller than in the younger embryos and an *ectoptic zone* begins to emerge from its periphery. As yet these changes are conspicuous only dorsally between the optic vesicle and the thalamencephalon (16), and to a less degree ventrad immediately in front of the mammillary region (17). The dorsal element is the telencephalon (19), the ventral corresponds in general to the infundibular region (18). The mammillary region and the thalamencephalon have increased in size and form well-marked triangular prominences in lateral view. The midbrain (15) is a well-marked dilatation, triangular in form, defined by conspicuous isthmian furrows (22, 23) which all but meet ventrally in the angle formed by the second flexure of the neuraxis. The arched form of the hindbrain has been mentioned; its vertical diameter is increased by a ventral projection at the level of the quintal ganglion (3), the pontine angle. Thus it appears that a projection of this region long antecedes the development of the pontine flexure. In lateral view, the three segments with their oblique separating furrows are more conspicuous than in the younger embryos. They are especially prominent ventrad, which would seem to imply that their increasing definiteness is associated with the bending of the hindbrain. The ganglia are attached dorsally in the furrows; the

profundus (3a) between the first and second segments (31, 12); the quintus (3) between the second and third (12, 13); the acoustico-facial (4) immediately behind the third. Ventrally the second segment shows signs of subdivision. Barely seen in embryo No. 188, in No. 548 it is marked by a vertical furrow ascending to the attachment of the quintal ganglion and dividing the segment into an oblique cranial portion (12a), extending completely across the neural tube and a triangular caudal fraction (12b) which forms the bulk of the pontine angle but is confined to the ventral region of the neural wall, being excluded from the alar portion by the oblique complete third segment. The myelencephalon has seven neuromeres. These contrast sharply with the foregoing by their vertical position. The oblique metencephalic segments are now continuous with the neuromeres of the myelencephalon; that they form a homodynamous series is certainly not supported by the evidence of their development in the cat, in fact the heterogeneity of these elements seems as clearly given by their ontogeny as by the diversity of the peripheral nerves with which they are associated in the adult.

Embryo of Sixteen Somites.—(Plate XXXV.) The neural tube is closed and completely separated from the ectoderm except in the region of the fossa rhomboidalis. The flexure at the posterior isthmian sulcus (23) has increased and the nuchal bend is now present. In the hindbrain the region of the second (12) segment projects ventrally and forms the pontine angle. The optic vesicles (1) are still further reduced in size, absolutely as well as relatively, and there is formed both ventral and dorsal to the vesicle a considerable zone which represents the extension of the telencephalon (19) and infundibular region (18) of the preceding embryos. The coalescence between the mammillary region (17) and the thalamencephalon (16) has increased; and they now form a well-marked segment between the midbrain and the derivatives of the optic vesicles (1).³ The mesencephalon (15) is triangular and markedly compressed ventrad. The segments of the hindbrain are less oblique than in preceding embryos. The first (31) is large, the second (12a, 12b) forms the prominence of the pontine angle, is ventrally subdivided and its second segment now extends farther dorsad. The third segment (13) is narrow. The ganglia retain their primitive intersegmental positions.

Embryo of Seventeen Somites.—(Plate XXXVI.) The reduction of the optic vesicle (1) continues. The telencephalon (19) forms a promi-

³ In this respect this embryo corresponds closely to the four-millimeter sheep embryo figured by Neumayer—*Studien zur Entwicklungsgeschichte des Gehirns der Säugethiere. Festschrift zum Siebenzigsten Geburtstag von Carl von Kupffer. Taf. XLVIII, fig. 4. Jena, 1899.*

ment convexity in front of the optic vesicle. Near its upper limit there is a point where the ectoderm is still adherent (8). The area which we have termed infundibular region (18) is very large and has a pointed apex directed caudad. The mammillary region (17) has increased in size but otherwise closely resembles that of the fourteen somite embryos. The same is true of the mesencephalon (15). The hindbrain is markedly enlarged in its vertical diameter. The pontine angle has increased in prominence. The first hindbrain segment (31) is broad and prominent; the second (12) is subdivided by a deep sulcus; its posterior moiety (12*b*) has a considerable vertical extent but is now fusing dorsally with the third segment (13) which remains narrow but has increased greatly in height, forming indeed the apex of the pontine angle. The quintal ganglion (3) retains its intersegmental position, but that of the profundus (3*a*) is beginning to shift caudad and is now in part attached to the second segment (12*a*). The cranial extremity of the myelencephalon has increased markedly in vertical diameter and is beginning to be assimilated to the hindbrain; it shows a prominence of the roof at its commencement which is separated by a depression from the remainder of the roof-plate. This embryo showed some degree of side-to-side compression with resulting diminution of the relief of its lateral walls and an exaggeration of the projections in the dorsal and ventral midline.

Embryo of Nineteen Somites.—(Plate XXXVII.) The forebrain is defined by a well marked anterior isthmian constriction (22) which is practically in line with the venter of the hindbrain. The thalamencephalon (16) has enlarged and is separated from the telencephalon (19) by a shallow but definite furrow (26) extending from the dorsal midline, obliquely over the lateral surface of the brain to the depressed area immediately behind the optic vesicle where the thalamencephalon merges into the relief of the regio mammillaris (17). The latter has not increased in size and is separated from the regio infundibularis (18) by a shallow furrow; it is also distinguished by its greater lateral prominence. The remainder of the forebrain comprises the optic vesicles and an ectoptic zone surrounding them. The latter has greatly enlarged in its dorsocephalic portion, the telencephalon (19), which now forms the extremity of the brain. The regio infundibularis shows but a moderate increase in size. New conditions are initiated ventral to the optic vesicles, which now begin to retreat from the margin of the brain, leaving a narrow strip of tissue through which the infundibular region and telencephalon are continuous. This condition is more clearly shown in the model of the lumen.

The midbrain (15) is little changed as yet but is beginning to show

a lengthening of its dorsum which becomes marked and characteristic in later stages. In the hindbrain the pontine angle has increased in prominence. The first segment (31) is very large, the second (12) is ventrally subdivided into two, as is also the third (13). The sulci corresponding to these subdivisions extend dorsad only so far as the ganglia. Behind the third of the original segments of this region is one small projection confined to the ventral portion of the neural tube. This is followed by the vertical myelomeres corresponding to the mesodermic somites.

The large ganglia are shifting their points of connection with the neural tube and are now attached somewhat above the middle of its lateral wall. The profundus (3a) has shifted to the middle of the second segment, lying at the extremity of the sulcus which marks its ventral subdivisions. The quintal ganglion (3) has lost its primitive intersegmental position and adheres to the cephalic part of the third segment. These two ganglia are thus beginning to approach one another. The acoustico-facial (4) occupies the interval between the fourth segment (14) and the first myelomere (24).

Embryo of Twenty-one Somites.—(Plate XXXVIII.) The forebrain differs from that of the preceding embryo notably in the enlargement of the infundibular region (18) as well as in the increase of the ectopic zone as a whole. The optic vesicles have receded further from the ventral margin and a broader strip connects the infundibular region with the telencephalon (19). The ectoderm is adherent to the latter at a point corresponding to the somewhat angular junction of the ventral and cranial margins of the pallium. On either side of this line of adherence the neural tube gives rise to projections (27), not quite symmetrical, which bear the same relation to the medullary plate as the large ganglia at their inception. The element of the right side, which is somewhat the larger, contains in its interior two small cavities which, however, do not communicate with the lumen of the neural tube. We are unable to offer any suggestion as to the significance of this structure, nor have we found in younger or older embryos of the cat any corresponding structure.

The thalamencephalon (16) and mammillary region (17) together form a well-defined segment of triangular outline interposed between the foregoing structure and the midbrain (15). The latter shows an increase of length in its dorsal zone. The hindbrain differs but little from that of the preceding embryo. Its first segment (31) is somewhat compressed; the second (12) is subdivided ventrally and the profundus ganglion (3a) is attached at about its vertical middle, close to its caudal

margin. The third segment is also subdivided ventrally; the attachment of the quintal ganglion (3) extends close to its cranial border. These two ganglia are thus approximated and on the point of union which is ultimately effected in embryos of twenty-six somites. The third segment is followed by a slight prominence (14) confined to the ventral region of the neural tube and less clearly marked off from the myelencephalon than in the preceding embryo. Above it is the acoustico-facial ganglion (4). The relief of the following neuromeres is faint and to be made out only with great difficulty in this embryo. The model of the lumen (Plate XLI) corroborates the description we have given of the external relief, but in addition presents one or two details which are not perceptible from the surface. The plica ventralis encephali by its broad summit forms the floor of the midbrain. Its anterior angle, the tuberculum postero-superius of authors, juts forward prominently. Immediately below is the recess of the mammillary region (17) bounded ventrally by the tuberculum postero-inferius (2). Ventral to this again is the large triangular cavity of the infundibular region (18). Its ventral wall shows a moderate thickening, torus postopticus, in front of which is the shallow preoptic recess, from which the lamina terminalis extends forward and upward to a point at which the ectoderm (7) is adherent.

We have now completed the record of our objective findings on the basis of which we propose to discuss the problem stated in our opening paragraph; we shall endeavor in the course of this discussion to compare our results with those of other students only in so far as they have dealt with mammalian embryos of corresponding stages of development. Unfortunately the number of detailed descriptions of such embryos is not large. We have not, therefore, attempted any general comparison of the ontogeny of the mammalian neuraxis with that of better known forms, except in a few instances when it has a direct and important bearing upon our problem.

GANGLIONIC CREST

It has already been stated that the medullary plate primitively lacks a precise boundary and passes by a gradual thinning into the somatic ectoderm (Plate XXII, Fig. 1, 28). Prior to closure, however, and this is true of the head as well as the trunk, an abrupt demarcation is established and the somatic ectoderm joins the medullary plate at its dorso-median angle (Plates XXVIII-XXX). This remodeling of the neuro-somatic junction is progressive cephalo-caudad, and is completed in each

region before closure occurs. Coincidentally the medullary plate narrows markedly so that it is probable that the primitive region of transition is thinned out and added to the somatic ectoderm. When closure is effected the ectoderm is closely applied to the concave dorsum of the neural tube and is continuous from side to side, without median attachment to the neuraxis, and with no intervening cells (Plate XLI). We would emphasize these facts, for they patently exclude the interpretation of the ganglionic crest of the trunk as an element intermediate between the general ectoderm and neural tube, and primitively independent of the latter. In this point our observations are in accord with the sections of the cat figured by Fleischmann⁴ and of the human embryo by Felix⁵ and agree with Neumayer's⁶ observations upon the trunk region of reptiles. It would seem to follow, therefore, that the ganglionic crest of the cat is a derivative of the neural tube, and this view acquires an antecedent probability from the occasional retention of afferent ganglion cells in the neuraxis of the adult, as in *Amphioxus* and Teleosts, and in the mesencephalic root of the trigeminus of mammals.

In the cat, the ganglionic crest is formed in the trunk by a simple delamination of the dorsal less regularly arranged cells at the summits of the neural folds. Shortly after closure a minute cleft appears on each side and advances towards the midline, until the crests are attached only by a narrow median strand. Again our results are concordant with those of Neumayer for reptiles.

Sometimes, and not always symmetrically, prior to closure, a faint furrow appears on the ental surface of the neural fold close to the junction with the somatic ectoderm. This we have taken to indicate some small degree of lateral movement of the cells at this point as though to form an evagination. The process is abortive but suggests that in the derivation of the ganglionic crest from the neural tube delamination may have been substituted for evagination, and a solid anlage may have replaced a hollow one, as elsewhere in the ontogeny of forms rich in cells.

Farther cephalad the evagination becomes conspicuous. In the acoustico-facial region (Plates XXVI and XXX) there is a shallow oblique furrow unaccompanied by evagination and the ganglion seems to agree

⁴ A. FLEISCHMANN: *Embryologische Untersuchungen. Erstes Heft. Taf. II, figs. 4-6; Taf. III, figs. 3-12. Wiesbaden, 1889.*

⁵ W. FELIX: "Die Entwicklung der Harn und Geschlechtsorgane in Keibel and Mall," *Handbuch Entwicklungsgeschichte des Menschen. Figs. 522, 525, 528-530. 1911.*

⁶ L. NEUMAYER: "Zur Morphologie des Central Nervensystems der Chelonier und Crocodiles." *Aus Voeltzkow Reise in Ostafrika in den Jahren. 1903-1905. Band IV. 1914. Über den Schluss der Sekundären Medullarfurche und die Genese der Neuralleiste. Verhandl. Anat. Ges. 22. 1913. "Histogenese und Morphogenese des peripheren Nervensystems, der Spinalganglien und des Nervus sympatheticus." Handbuch der Vergleich, und experiment. Entwicklungslehre der Wirbelthiere. Hertwig. 1906.*

with the more caudal ones in owing its origin to delamination from the medullary fold.

In the quintal anlage the sulcus is conspicuous and its horizontal portion is associated with a ridge-like projection (Plates XXV and XXIX) in the angle between neural plate and somatic ectoderm, which yet reveals its closer affinity to the neural plate by blending with it at both of its extremities in the four-somite embryo. It then appears subtended by a longitudinal furrow, and differs more in size than in any essential character from the more caudal ganglionic crest.

Finally, the optic vesicle, a pure evagination, presents at an early stage much resemblance to the quintal anlage (Plates XXIV and XXVIII), from which it differs chiefly in size and in the more ventral position of its sulcus.

We see in these anlages a series of structures, passing by gradations from the delaminated ganglionic crest through the acoustico-facialis and quintus to the optic vesicle, which is formed by evagination alone. It seems to us, therefore, that the primitive neural plate in the cat gives rise both to the neural tube and to the ganglionic crest, the latter being a derived and secondary element and not a coördinate intermediate between the medullary plate and the somatic ectoderm. In the forebrain elements equivalent to the ganglionic crest are retained in the wall of the vesicles and constitute the dorsal region of the neural plates, for if the crest secondarily separates from the neural tube, in regions where such separation fails to occur, it is more probable that the crest is included in the brain than that it has been absolutely suppressed. *Accordingly, the analysis of the prosencephalon is not to be attempted in terms of the basal and alar plates alone, as has been customary since His, but must include a dorsal or ectal strip equivalent to the ganglionic crest along its convexity, and this must include at least as much of the brain wall as lies ectal to the optic sulcus.* This ganglionic element (the primitive optic vesicle) at four somites forms the cephalic extremity of the neural fold, and arches ventrad to the floor. If our argument is correct, the optic vesicle and the ectoptic structures, whether above, in front or below the optic region, must be considered of ganglionic equivalency, a conclusion which entails a revision of His's analysis of the brain.

The question of the substitution of mesectoderm for a neurogenic ganglionic crest in the proötic region in mammals can hardly, we believe, receive an affirmative answer in view of the conditions observed in the cat, for we find quite generally the separation between ectoderm and neural tube clean cut, and the space between these structures unoccupied by cells. The mesectoderm of the ichthyopsid and sauropsid embryo,

described by Neal,⁷ Johnston,⁸ Neumayer,⁹ and others, is, perhaps, not altogether fortunately designated ganglionic crest, for these investigators describe it as taking origin from an intermediate element, interposed between neural tube and ectoderm and derived from both of these structures. On the other hand, the ganglionic crest in the trunk in sauropsids (Neumayer) as well as in the cat is a derivative from the neuraxis, as in the latter form are also the cranial ganglia. It would seem, therefore, that having slightly different derivations the mesectoderm and the ganglionic crest ought not absolutely to be homologized. Neumayer has formulated this standpoint clearly, as follows:

"So zeigt sich im Aufbau des cerebralen Teiles der Ganglienleiste, soweit sie dem Archencephalon und dem praeötischen Gebiet des Hirns angehört, ein Verhalten, das sich morphogenetisch wesentlich von den einfacheren Verhältnissen im postotischen und spinalen Gebiet unterscheidet. Ich kann mich über die Vorgänge hier im Anschluss und die oben (p. 452) gemachten Angaben in Kürze fassen. Entsprechend dem im spinalen Gebiete anders erfolgenden Verschlusse des Medullarrohres wird das zum Aufbau der Ganglienleiste notwendige Zellmaterial bei *Crocodylus madagascariensis* und *Emys lutaria* nur vom Dache der Medullaranlage geliefert; die so entstandene postotische Ganglienleiste ist demnach wesentlich verschieden von der cerebralen praeötischen. Sie entbehrt des primären, aus Exoderm und Medullarwand entstammenden Anteils und enthält nur jene Elemente, welche in die cerebrale praeötische Ganglienleiste sekundär eintreten.

"Hiezu kommt auch ein Unterschied in den Leistungen der beiden Ganglienleisten: von ihnen liefert die cerebrale, praeötische in gleicher Weise Nerven und mesodermales Gewebe für das präotische Kopfgebiet, während das spinale, postotische Ganglienleistensystem einzig Nervengewebe aus sich hervorgehen lässt."

In the cat, the paraxial mesoderm of the head is abundant and very early becomes loosely arranged, extending dorsad and forcing its way into the cleft between the ectoderm and the dorsum of the neuraxis. We have stated that at the time of separation of these two structures, their demarcation was sharply defined and without intervening cells, nor were we able to find mesoderm at any time in this situation, which was not continuous ventrally with the general mesoderm of the head. This lack of evidence of the formation of mesectoderm in the cat inclines us strongly to accept Neumayer's distinction of a primary and secondary proötotic ganglionic crest, the former (mesectoderm) being undeveloped

⁷ H. V. NEAL: "The Segmentation of the Nervous System in *Squalus Acanthias*," Bull. Mus. Comp. Zool. Cambridge, Mass., Vol. XXXI, No. 7. 1898.

⁸ J. B. JOHNSTON: The Nervous System of Vertebrates. Philadelphia, 1906. "The Morphology of the Forebrain Vesicle in Vertebrates," Jour. Comp. Neurol. and Psychol., Vol. XIX, No. 5. 1909.

⁹ L. NEUMAYER: *Op. cit.*, 1914, p. 460.

in the cat, the latter arising from the neuraxis by delamination combined with the evagination constitutes the cranial ganglia, and at the extreme cephalic pole, failing, we believe, to separate remains incorporated as the primitive optic vesicle.

CLOSURE OF THE NEURAL TUBE

At the extremities of the axis the elevation of the neural folds may be resolved into two acts. Cephalad the median or basal portion is first elevated, while laterad the plate has still a horizontal direction. This condition is present in the embryos of two and three somites (Plate XXIII, Fig. 2). The condition seems to be the effect of modeling of the ectoderm upon the paraxial accumulation of mesoderm. At four somites (Plate XXVII, Fig. 1) the fold is erect in its whole extent and rises well above the mesoderm, the somatic ectoderm being closely applied to the neural plate in its dorsal half. Caudad the process differs; the lateral part of the plate is first elevated at some distance from the median line (Plate XXVII, Fig. 1, and Plate XXVII, Fig. 2) and forms a low wall for the broad rhomboid fossa. When the tube closes here, its diameter is much less than the width of the fossa would lead one to expect. This is suggestive of the possibility that the lengthening of the tube is not due alone to axial growth, but may be assisted by a rearrangement of the material of the neural plate in the sense of a shift towards the median line so that the plate is extended caudad as it narrows. The elevation of its lateral margins is associated with the moderate entrophy of the blastoderm and the early completion of the amnion at its caudal end.

The neural folds first meet in the region of the future mesencephalon, but their closure is not simply progressive from this point in both directions. On the contrary, it is incident simultaneously at several points which may be rather widely separated. In the eight-somite embryo, in addition to the closure of the midbrain, which extends from the optic anlage to the quintal ganglion, there is a second closure between the quintal and acoustico-facial anlages; and again, after an interval, at a third point the folds seem on the verge of meeting (Plate XXVII, Fig. 2). There is also some fusion cephalad at the ventral margin of the neuropore. This is of some theoretical importance and diminishes the significance of the neuropore as a morphologic landmark. The gaping of the tube in the region of the optic and quintal anlages suggests that such structures in some way delay closure, but as the neurosomatic junction is now sharply defined, it is difficult to believe

that this is in the interests of a hypothetical inrolling either here or in the optic vesicles.

At nine somites the neuropore is shorter, by reason of closure at both its ends but chiefly caudad. Its extremities now lie in the same vertical plane. The quintal hiatus is closed at two intermediate points, presenting three small orifices (Plate XXXI, Fig. 1). Caudad to it a short segment of the tube has closed. A small hiatus is present in the region of the acoustico-facial ganglion. This embryo, therefore, gives additional evidence of the retardation of closure in regions of large ganglia.

Further irregularities are shown in Plate XXXII, Fig. 1, and Plate XXXIII, Fig. 1, in the trunk region, and in Plate XXXIII, Fig. 2, and Plates XXXIV-XXXVI in the anterior neuropore. As this latter closes ventrally as well as caudally, and irregularly in the intermediate portion, it seems difficult to consider that its region of latest obliteration has any fundamental morphological importance or can at all properly be used to determine the cephalic extremity of the neuraxis, which is certainly deflected ventrad. Further, if the wall of the neural tube is divided into basal and alar plates, its cephalic pole ought to be the most cephalic point in their line of union, *i. e.*, in the terminology of His, the cephalic extremity of the sulcus limitans, when this sulcus can be recognized. It would seem, therefore, that wherever this point is localized it cannot be situated in the raphé which throughout its length is assumed to be a suture between the summits of the alar plates, or, if our interpretation prove correct, in the forebrain, between retained ganglionic zones. To accept the last point of attachment of the ectoderm marked by the recessus neuroporicus as the extremity of the axis, implies that the raphé below this point is a suture between the basal plates, although it has never been shown that they were primitively cleft; further it would seem the necessary consequence of the acceptance of this landmark (recessus neuroporicus) that the mammillary and infundibular regions and the ventral half of the optic vesicles themselves were derived from the basal laminae. To accept the recessus neuroporicus as the ontogenetic pole of the brain seems, therefore, to disregard the ventral deflection of the neuraxis and the composition of its wall of basal and alar plates. In His's three months' embryo (No. 7 of Ziegler's series of models) the sulcus limitans passing forward in the midbrain is continuous with a furrow which arches ventrad and reaches the midline immediately in front of the oculomotor nucleus. This, we believe, is actually the sulcus limitans demarcating the alar and basal laminae and reaching the midline where the latter ceases to give evidence of its existence, *i. e.*, immediately in front of the oculomotor nucleus, the most

cephalic structure which by its derivatives can be assigned to the basal plate. A second furrow, not connected with the foregoing, extends across the wall of the thalamencephalon, nearly horizontally, to the foramen of Monro. This sulcus of Monro, His interpreted as the continuation of the sulcus limitans. The interpretation we have suggested is at least as concordant with his observations and does not entail morphologic impossibilities.

In order to facilitate the comparison of these divergent interpretations we subjoin two schemata; the first (Fig. 1) is based on the well-known

FIG. 1.—*Schemata of the composition of the encephalon in terms of basal and alar plates of His*

1. Basal plate. 2. Alar plate. 3. Sulcus limitans.

figure of His; the second (Fig. 2) illustrates the region of the neuraxis which must be assigned to the ganglionic crest on the basis of our interpretation. We have retained from His's figure the sulcus limitans as it appears in later stages of development for the purpose of defining the basal plate, although in the period of development of the cat covered by our series of embryos this furrow is not even indicated.

PROSENCEPHALON

The elevation of the neural folds at their cephalic extremity is accomplished in two phases, affecting first their basal, later their alar portions

(Plate XXII, Fig. 2; Plate XXIII, Fig. 2, and Plate XXVII, Fig. 1). The process is completed in the embryo of four somites. Two conspicuous landmarks are now present—the tubercle of the floor and the optic sulcus. Corresponding to the latter is a thick-walled evagination, the optic vesicle (Plate XXIV). This anlage resembles those of the quintal and acoustico-facial ganglia and is peculiar only in the course of the sulcus, which here approaches the floor at its cephalic and not its caudal extremity, as in the case of the other ganglia. The tubercle of the floor intervenes between the terminal portions of the optic sulci. Ventrad it

FIG. 2.—*Schema of the composition of the encephalon in terms of basal and alar plates and ganglionic zone*

1. Basal plate. 2. Alar plate. 3. Sulcus limitans. 4. Ganglionic zone.

is in relation with the blind extremity of the foregut; the stomodæum approaches, but hardly reaches it, from in front. By means of these relations the tubercle is easily recognized in succeeding stages, when ultimately it forms a transverse ridge intervening between the mammillary and infundibular regions.

The wall of the optic vesicle is divided by the sulcus into a ventral portion adjoining the floor plate and an ectal zone extending to the neurosomatic junction, and therefore forming the summit of the medullary fold and later the lateral lip of the neuropore. Ventrally this zone joins the tubercle of the floor, which so constitutes the ventral neuropore

lip. It is obvious, but important to note, that the optic vesicle at this stage forms the cephalic extremity of the neuraxis. Preoptic structures in consequence must be derived secondarily, either from the ectal zone of the optic vesicle, or by inrolling of somatic ectoderm at the neuropore. Of the latter process there is no evidence in the cat, and this alternative seems excluded by the abrupt character of the neurosomatic junction. We may, therefore, confine our attention to the optic vesicles and summarize the changes by which they give rise to an ectoptic zone which includes the anlagen of the thalamencephalon, telencephalon and the infundibular region. Most striking is the progressive and absolute reduction in size of the optic vesicles, which are actually smaller at the stage of sixteen somites than they were at eight. Coincidentally they cease to occupy the whole vertical extent of the wall of prosencephalon and become relegated to a ventral position. The nature of these changes, especially the reduction in size of the optic vesicle, permits of but one interpretation, namely, that the ectoptic zone is formed at the expense of the vesicle. A similar remodeling of the ventro-caudal portion of the vesicle gives rise to the infundibular region.

As the tubercle of the floor constitutes the extremity of the floor-plate and at the same time the primitive ventral lip of the neuropore, it is of prime importance to ascertain its position in subsequent stages of development. It is easily recognized by its thickness and its interposition between the ventral ends of the optic sulci. At first, also, it is abutted upon by the *cul-de-sac* of the foregut which, however, rapidly recedes from it, at eight somites only reaching its caudal extremity and at ten somites terminating beneath the midbrain.

In Plate XXXIX, Fig. 1, the ental surface of the brain is shown by a mid-sagittal section of an embryo of eight somites. The tubercle of the floor (2) forms the ventral lip of the neuropore; its cephalic extremity is connected with the suprasulcal portion of the optic vesicle of each side. From the parieties it is separated by the shallow prolongation of the optic sulcus which terminates in a depression of the floor, immediately behind the tubercle and above the foregut. There is, as yet, no corresponding elevation of the ectal surface; the recess is the first evidence, in our series of the mammillary region (17). In the embryo of ten somites (Plate XXXIX, Fig. 2) these fundamental relations are still recognizable, although important changes have supervened. Coincidentally with the ventral deflection of the extremity of the neuraxis, the tubercle of the floor (2) has assumed a vertical position. A considerable degree of closure has been effected ventrally in the anterior neuropore, so that the tubercle no longer constitutes its ventral lip. The mammil-

lary recess (17) is better defined, the mammillary eminence projects laterad but scarcely as yet forms a prominence in the mid-ventral line. As a consequence of closure ventrad in the neuropore and of the ventral deflection of the optic vesicles, a prominent angle is formed immediately below the tubercle of the floor, which now intervenes between the two recesses, the mammillary above and the one just described, the infundibular (18), below. The optic sulcus meets the floor-plate in the infundibular region, but a shallow prolongation can still be followed beside the tubercle of the floor. In the embryo of twelve somites (Plate XI, Fig. 1), slight changes have supervened. The floor as a whole is thinner, which may be taken as an expression of the expansion of the cavity, and the tubercle of the floor (2) is no longer a conspicuous thickening. The infundibular region (18) has increased in size and its cavity is more widely confluent with that of the optic vesicles. Coincidentally the terminal portions of the optic sulci undergo reduction and lose their intimate relation to the tubercle of the floor. A very faint furrow may be followed from the optic vesicle across the parieties just above the remnant of the tubercle, while the main line of the optic sulcus extends into the infundibular region. The tubercle of the floor is now losing its demarcation from the parieties with the effacement of the primitive ventral segment of the optic sulcus, and from this period appears as a transverse ridge intervening between the mammillary and infundibular regions. It is, therefore, evident that the mammillary region arises from the cephalic extremity of the primitive floor-plate and that the infundibular region is a derivative of the primitive optic vesicles.

Not only ventrally but also dorsally the periphery of the optic vesicle undergoes a remodeling and important new conditions are established. First, a prominence is formed immediately in front of the anterior isthmian sulcus, the thalamencephalon, and subsequently the telencephalon emerges in front of this. The two elevations are separated by a slight depression, the first indication of the velum transversum, from the stage of thirteen somites, the earliest period at which the telencephalon is recognizable. Both of these structures appear in the lip of the anterior neuropore prior to its closure in their respective regions, and are accompanied by a recession of the optic vesicle from the margin of the medullary plate and, what is of major importance, an absolute diminution in the size of the vesicle. This is well marked in the period of from ten to sixteen somites when the thalamencephalon, telencephalon and infundibular region are well defined and the optic vesicle reaches the margin of the neuraxis at only a single point between the infundibular region and telencephalon. From this period the ventral pole of the vesicle slowly

recedes from the margin, and the telencephalon becomes continuous with the infundibular region. There has thus been formed from the periphery of the vesicle a series of derivatives which constitute an ectopic arcade and in each case the process has been the same, a remodeling of the primitive optic vesicle, so that its central region ultimately constitutes the definitive vesicle, while its periphery becomes allotted to the anlagen of the other elements of the prosencephalon which are, therefore, ectopic in their arrangement and cannot be reduced to a linear series of neuromeres referred to the longitudinal axis of the neural tube. We have now summarized the ontogeny of the forebrain as it appears in our series of embryos of the cat. It is hardly necessary to add that we are not offering these conclusions as an explanation of the phylogeny of the mammalian brain.

MESENCEPHALON

Closure of the neural tube and its separation from the ectoderm are accomplished first in the midbrain. As elsewhere, the resulting roof is concave. The concavity is present in the whole length of the neuraxis but its degree increases cephalad and is most conspicuous in the forebrain. In the mesencephalon it is marked and persists to the stage of sixteen somites; it is associated with a sagittal ridge which depends into the lumen entally. In section the ridge is often constricted at its base of attachment and occasionally a fragment of it is found separate as a small group of cells within the neural canal. In the embryo of eight somites the mesencephalon (15) is closed in half of its extent and forms the highest region of the neural tube (Plate XXVII, Fig. 3). At nine somites the closure is complete, the midbrain has lengthened and its height has markedly diminished (Plate XXXI, Fig. 2, 15). A comparison of these two embryos throws some light upon the nature of these changes. The distance between the quintal anlage and Sessel's pocket is the same in both models, but the interval between the optic vesicle and the quintal ganglion has markedly increased, the axis of the optic vesicle has altered and the forebrain has come to project strongly ventrad at right angles to the rest of the neuraxis. These facts taken in conjunction with the diminished height of the midbrain cannot be adequately interpreted on the principle of unequal growth alone. It must be taken as the expression of a remodeling of the whole region, in particular a lengthening of the dorsal portion of the midbrain without corresponding increase of its ventral parts, in consequence of which the optic vesicle has not only been displaced but rotated through 90° and the neuraxis has been bent ventrad in the region of the forebrain. There

are no signs of compression in the mesencephalon but the slight bulge of the mammillary region is, perhaps, the result of flexure.

In embryos of ten to twelve somites (Plates XXXII and XXXIII), the mesencephalon acquires a triangular profile, demarcated from the hindbrain by a shallow constriction which gradually becomes pronounced and has a vertical direction (the posterior isthmian sulcus 23). The anterior isthmian sulcus (22) is horizontal and forms a sharp boundary against the mammillary region but becomes shallow cephalad near the pole of the optic vesicle. A slight transverse depression of the roof separates the midbrain from the thalamencephalon (16). The walls are convex and entally show nothing which can be taken for the sulcus limitans of His. Ventrad the isthmian sulci converge to the angle made by the forebrain with the floor of the neuraxis.

In the thirteen and fourteen somite embryos (Plate XXXIV), the mesencephalon is gradually bent ventrad and comes to form the most cephalic point of the brain. This bend is associated with clear evidences of compression in the floor of the hindbrain. In the sixteen-somite embryo (Plate XXXV), the mesencephalon has been carried slightly beyond the crown of the cephalic arch and conjointly with the prosencephalon (19) makes a right angle with the hindbrain. The isthmian sulci now converge at an acute angle and the midbrain reaches the ventral margin only by its pointed extremity. At this stage, a nuchal bend is well defined and the effects of compression upon the mesencephalon are at a maximum. From this period to that of twenty-one somites, the midbrain lengthens in its dorsal segment and chiefly in a cephalic direction, as is shown by the alteration in the angle at which the anterior isthmian furrow meets the floor as well as by the increased flexure of the forebrain (Plates XXXVI-XXXVIII). We have described the midbrain as a single segment without subdivision into neuromeres, for, though we have searched for evidence of a constriction, we have been able to find none in any of our embryos save that of ten somites, No. 476, and here with less certainty than could be wished. A faint concavity was present between the isthmian furrows and inclined so that its continuation would have bisected their angle and divided the midbrain into a slightly larger cephalic and smaller caudal portion. It was confined to the dorsal portion of the neural plate without, however, causing a depression in the roof. The brain in this embryo was somewhat spirally twisted to the right and the depression in question was not quite symmetrical on the two sides. For this reason and because in all our other embryos the midbrain attains its greatest width precisely in the region where this exceptional furrow appears, we are inclined to attribute its presence to the unusual twist of the head.

RHOMBENCEPHALON

The large ganglia of the quintus, acoustico-facialis and profundus, which develop in the order named, are associated in their inception with sulci. These, beginning near the neurosomatic junction, and at first parallel to it, eventually turn ventrad pursuing an oblique course across the medullary fold. Each furrow is thus composed of a cephalic segment, intimately concerned in the formation of the ganglia and a caudal portion which, becoming broad and shallow, occasions a dilatation of the neuraxis. As the tube closes three oblique segments are formed. In the embryo of ten somites (Plate XXXII, Fig. 2), where we were first able to recognize the profundus anlage distinctly, four segments were present. The first (31) is triangular in form with base ventrad, extending from the posterior-isthmian sulcus to the oblique furrow at the summit of which is the profundus ganglion (3a). This element has no ganglion associated with it developmentally but owes its demarcation to the establishment of a caudal boundary of the midbrain in the posterior isthmian sulcus. It is followed by three oblique ganglionic segments which are the expression of the oblique caudal portions of the ganglionic sulci in the interior of tube. Externally three oblique intersegmental constrictions are present, so that the third ganglionic segment lacks a caudal boundary and merges into the relief of the myelencephalon. The ganglia are situated at the summits of these furrows and are accordingly intersegmental in their points of attachment, as was first pointed out by Miss Platt.¹⁰

This configuration is retained to the stage of thirteen somites. In these embryos, and very vaguely in the more advanced embryos of twelve somites, the surface of the neural tube behind the ganglionic segments becomes marked by alternating constrictions and dilatations. These, in marked contrast to the ganglionic segments, are vertical in position and correspond to the mesodermic somites which abut upon the neuraxis in the intervals between the dilatations. These vertical segments are undoubtedly the myelomeres of McClure¹¹ and are widely different structures from the oblique ganglionic segments of more cephalic position. Primitively the two series are separated by a considerable interval which is not effaced until the stage of fourteen somites, the most cephalic myelomeres being relatively late in appearance. Their retardation, we believe, is due to the small size of the mesodermic somites in this region,

¹⁰ J. B. PLATT: "A Contribution to the Morphology of the Vertebrate Head based on a Study of *Acanthias Vulgaris*." Jour. Morph., Vol. V. 1891.

¹¹ C. F. W. MCCLURE: "The Primitive Segmentation of the Vertebrate Brain." Zool. Anz. Jahrg., Vol. XII. 1889.

so that they are slower in producing an effect upon the modeling of the neuraxis. There is besides some evidence in the cat that somites are added at the cephalic end of the series, which also would serve to explain the retardation of the corresponding myelomeres. We are assuming that the segmentation of the neuraxis into myelomeres is ontogenetically secondary to the segmentation of the mesoderm, a view which receives support from the fact that the number of myelomeres always lags behind that of the somites, as well as by the fact that where the somites are small and possibly retarded in appearance developmentally as in the region just considered, there also the myelomeres are late in appearing.

It is possible, therefore, to recognize two principles of segmentation in the deuterencephalon; the first incident to the formation of the cranial ganglia, the second associated with the segmentation of the mesoderm, for it is to be noted that the appearance of the ganglionic segments long antedates the branchiomic segmentation. When, therefore, the series of myelomeres becomes continuous with the ganglionic segments the result is not a meristic series of equivalents but comprises structures diverse in their genesis and heterogeneous in their products.

In the stage of fourteen somites, the boundary between these two series is gradually effaced and important changes supervene in the ganglionic segments. The first and second of these become subdivided ventrally. This is initiated in the first segment at the stage of fourteen somites, in the second segment at nineteen somites. The third maintains itself as a small dilatation immediately in front of the first somite. These changes coincide with the formation of the pontine angle, the surface of which is marked by five elevations corresponding to the third ganglionic segment and the subdivisions of the first and second. In addition a small prominence, corresponding to the first myelomere, is situated immediately caudal to the last of these elements and is also recognizable at twenty-one somites (Plates XXXVII and XXXVIII). If we now add to our reckoning the pre-ganglionic segment abutting upon the posterior isthmian sulcus, a total of seven elevations is reached for the hindbrain, a number within the limits of the count given by students of the region in mammals, variation in which might well depend upon the age of the embryo studied.

It would seem, therefore, that these elevations correspond to the neuromeres of authors. We have endeavored to show that they are secondary and heterogeneous.

ANNOTATIONS OF LEADERS ON ALL PLATES

1. Optic sulcus or vesicle.
2. Tubercle of the floor.
3. Quintal sulcus or ganglion.
- 3a. Profundus ganglion.
4. Acoustico-facial sulcus or ganglion.
5. Medullary plate or medullary fold.
6. Primitive groove.
7. Somatic ectoderm.
8. Anterior neuropore or its vestige.
9. Quintal hiatus.
10. Acoustico-facial hiatus.
11. Other hiatus in line of closure.
12. First ganglionic segment.
- 12a. First ganglionic segment: its cephalic portion.
- 12b. First ganglionic segment; its caudal portion.
13. Second ganglionic segment.
- 13a. Second ganglionic segment; its cephalic portion.
- 13b. Second ganglionic segment; its caudal portion.
14. Third ganglionic segment.
15. Mesencephalon.
16. Thalamencephalon.
17. Mammillary region.
18. Infundibular region.
19. Telencephalon.
20. Ganglionic crest.
21. Rhomboid fossa.
22. Anterior isthmian sulcus.
23. Posterior isthmian sulcus.
24. First myelomere.
26. Velum transversum.
27. Excrescence associated with vestige of anterior neuropore.
28. Region of transition between somatic ectoderm and neuraxis.
29. Mesoderm.
30. Entoderm.
31. Preganglionic segment of deuterencephalon.

PLATE XXII

SECTIONS OF EMBRYOS BEFORE AND AFTER SEGMENTATION

FIG. 1.—Transverse section of an embryo prior to the appearance of inter-somitic clefts.

Columbia Collection No. 550, slide 3, row 4, section 7. $\times 150$.

5. Medullary plate. 7. Somatic ectoderm. 28. Region of transition.
29. Mesoderm. 30. Entoderm.

FIG. 2.—Transverse section of an embryo of one somite.

Columbia Collection No. 594, slide 5, row 2, section 6. $\times 150$.

5. Medullary plate. 7. Somatic ectoderm. 28. Region of transition.
29. Mesoderm. 30. Entoderm.

FIG. 1

FIG. 2

PLATE XXIII

SECTIONS OF EMBRYOS WITH TWO AND THREE SOMITES

FIG. 1.—Transverse section of an embryo of two somites.

Columbia Collection No. 539, slide 5, row 4, section 4. $\times 150$.

5. Medullary plate. 7. Somatic ectoderm. 28. Region of transition, showing presence of a shallow furrow. 29. Mesoderm. 30. Entoderm.

FIG. 2.—Transverse section of an embryo of three somites.

Columbia Collection No. 593, slide 5, row 4, section. 4. $\times 150$.

5. Medullary plate. 7. Somatic ectoderm. 28. Region of transition. 29. Mesoderm. 30. Entoderm.

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FIG. 1

FIG. 2

PLATE XXIV

TRANSVERSE SECTION, EMBRYO OF FOUR SOMITES

Transverse section of the embryo of four somites, Columbia Collection No. 409, slide 5, row 6, section 10, passing through the optic vesicle. × 150.

1. Optic sulcus. 2. Tubercle of the floor. 5. Medullary fold. 7. Somatic ectoderm.

ANNALS N. Y. ACAD. SCI

VOLUME XXIV, PLATE XXIV

PLATE XXV

TRANSVERSE SECTION, EMBRYO OF FOUR SOMITES

Transverse section of the embryo of four somites, Columbia Collection No. 409,
slide 5, row 5, section 5, passing through the quintal anlagen. $\times 150$.

3. Quintal sulcus. 5. Medullary fold. 7. Somatic ectoderm.

ANNALS N. Y. ACAD. SCI.

VOLUME XXIV. PLATE XXV

PLATE XXVI

TRANSVERSE SECTION, EMBRYO OF FOUR SOMITES

Transverse section of the embryo of four somites. Columbia Collection No. 409, slide 5, row 2, section 10, passing through the acoustico-facial anlagen. $\times 150$.

4. Acoustico-facial sulcus. 5. Medullary fold. 7. Somatic ectoderm.

PLATE XXVII

RECONSTRUCTION OF NEURAXIS OF EMBRYOS OF FOUR AND EIGHT SOMITES

FIG. 1.—Reconstruction of an embryo of four somites.

Columbia Collection No. 409. $\times 210$. Reduced $\frac{3}{4}$.

FIG. 2.—Reconstruction of the neuraxis of an embryo of eight somites.

Columbia Collection No. 530. Dorsal view. $\times 210$. Reduced $\frac{3}{4}$.

FIG. 3.—Same reconstruction, lateral view. $\times 210$. Reduced $\frac{3}{4}$.

1. Optic vesicle. 2. Tubercle of the floor. 3. Quintal anlage. 4. Acoustico-facial anlage. 5. Medullary fold. 6. Primitive groove. 8. Anterior neuropore. 9. Quintal hiatus. 12. First ganglionic segment. 13. Second ganglionic segment. 15. Mesencephalon. 21. Rhomboid fossa. 31. Preganglionic segment of deuterencephalon.

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FIG. 1

FIG. 2

FIG. 3

PLATE XXVIII

TRANSVERSE SECTION, EMBRYO OF EIGHT SOMITES

Transverse section passing through the optic vesicles of an embryo of eight somites.

Columbia Collection No. 530, slide 5, row 3, section 3. $\times 150$.

1. Optic sulcus. 5. Medullary plate. 7. Somatic ectoderm.



PLATE XXIX

TRANSVERSE SECTION, EMBRYO OF EIGHT SOMITES

Transverse section passing through the anlage of the quintal ganglion of an embryo of eight somites.

Columbia Collection No. 530, slide 6, row 2, section 5. × 150.

1. Optic sulcus. 3. Quintal ganglion (the sulcus is still present). 5. Medullary plate. 7. Somatic ectoderm.



PLATE XXX

TRANSVERSE SECTION, EMBRYO OF EIGHT SOMITES

Transverse section passing through the anlagen of the acoustico-facial ganglia of an embryo of eight somites.

Columbia Collection No. 586, slide 4, row 2, section 1. × 150.

**4. Acoustico-facial ganglion (the sulcus is still present). 5. Medullary plate.
7. Somatic ectoderm.**

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PLATE XXXI

RECONSTRUCTION OF NEURAXIS OF EMBRYO OF NINE SOMITES

FIG. 1.—Dorsal view. Columbia Collection No. 531. $\times 210$. Reduced $\frac{3}{4}$.

FIG. 2.—Lateral view.

- 1. Optic vesicle. 3. Quintal ganglion. 4. Acoustico-facial ganglion.**
- 7. Somatic ectoderm. 8. Anterior neuropore. 9. Quintal hiatus.**
- 10. Acoustico-facial hiatus. 11. Another hiatus in line of union**
- of the medullary folds. 12. First ganglionic segment. 13. Second**
- ganglionic segment. 14. Third ganglionic segment. 15. Mesen-**
- cephalon. 16. Thalamencephalon. 17. Mammillary region. 20.**
- Ganglionic crest. 21. Rhomboid fossa.**

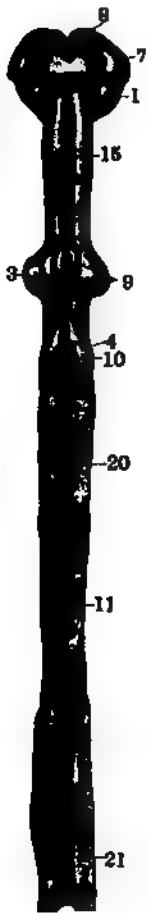


FIG. 1

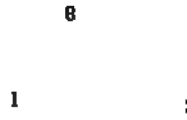


FIG. 2



PLATE XXXII

RECONSTRUCTION OF NEURAXIS OF EMBRYO OF TEN SOMITES

FIG. 1.—Dorsal view. Columbia Collection No. 476. $\times 210$. Reduced $\frac{3}{4}$.
The acoustico-facial ganglion and the ganglionic crest are omitted in this model.

FIG. 2.—Lateral view.

1. Optic vesicle. 3a. Profundus anlage. 3. Quintal anlage. 8. Anterior neuropore. 11. Hiatus in line of fusion of the medullary folds. 12. First ganglionic segment. 13. Second ganglionic segment. 14. Third ganglionic segment. 15. Mesencephalon. 16. Thalamencephalon. 17. Mammillary region. 21. Rhomboid fossa. 22. Anterior isthmian sulcus. 23. Posterior isthmian sulcus. 31. Preganglionic segment of deuterencephalon.

FIG. 1

FIG. 2

PLATE XXXIII

RECONSTRUCTION OF NEURAXIS OF EMBRYO OF TWELVE SOMITES

FIG. 1.—Dorsal view. Columbia Collection No. 534. $\times 210$. Reduced $\frac{3}{4}$. The ganglionic crest is omitted.

FIG. 2.—Lateral view.

1. Optic vesicle. 3a. Profundus anlage. 3. Quintal anlage. 4. Acoustico-facial anlage. 8. Vestiges of anterior neuropore. 11. Vestige of hiatus in line of fusion of medullary folds. 12. First ganglionic segment. 13. Second ganglionic segment. 14. Third ganglionic segment. 15. Mesencephalon. 16. Thalamencephalon. 17. Mammillary region. 18. Infundibular region. 20. Ganglionic crest. 21. Rhomboid fossa. 22. Anterior isthmian sulcus. 23. Posterior isthmian sulcus. 31. Preganglionic segment of deuterencephalon.

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FIG. 1

FIG. 2



PLATE XXXIV

RECONSTRUCTION OF NEURAXIS OF EMBRYO OF FOURTEEN SOMITES

Lateral view. Columbia Collection No. 548. $\times 210$. Reduced $\frac{1}{2}$.

1. Optic vesicle. 3*a*. Profundus ganglion. 3. Quintal ganglion. 4. Acoustico-facial ganglion. 8. Anterior neuropore, represented by a linear adhesion of the ectoderm. 12*a*. First ganglion segment; its cephalic portion. 12*b*. First ganglion segment; its caudal portion. 13. Second ganglionic segment. 14. Third ganglionic segment. 15. Mesencephalon. 16. Thalamencephalon. 17. Mammillary region. 18. Infundibular region. 19. Telencephalon. 20. Ganglionic crest. 24. First myelomere. 31. Preganglionic segment of deuterencephalon.

PLATE XXXV

RECONSTRUCTION OF NEURAXIS OF EMBRYO OF SIXTEEN SOMITES

Lateral view. Columbia Collection No. 551. × 210. Reduced ½.

- 1. Optic vesicle. 3a. Profundus ganglion. 3. Quintal ganglion. 4. Acoustico-facial ganglion. 12a. First ganglionic segment; its cephalic portion. 12b. First ganglionic segment; its caudal portion. 13. Second ganglionic segment. 14. Third ganglionic segment. 15. Mesencephalon. 16. Thalamencephalon. 17. Mammillary region. 18. Infundibular region. 19. Telen-cephalon. 20. Ganglionic crest. 22. Anterior isthmian sulcus. 23. Posterior isthmian sulcus. 31. Preganglionic segment of deuterencephalon.**

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1. *Journal of the American Medical Association*, 1997; 277: 1033-1036.

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1. *Chlorophyll a* (Chl *a*) and *Chlorophyll b* (Chl *b*) were determined using the method of Arar and Collins (1987). The concentration of Chl *a* and Chl *b* was expressed as $\mu\text{g mL}^{-1}$ of the sample.

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1. *Chlorophyll a* and *Chlorophyll b* were determined by the method of Arar and Collins (1971) using a Shimadzu 1601 UV-Visible Spectrophotometer.

PLATE XXXVI

RECONSTRUCTION OF NEURAXIS OF EMBRYO OF SEVENTEEN SOMITES

Lateral view. Columbia Collection No. 568. $\times 210$. Reduced $\frac{1}{2}$. The embryo is well preserved but deformed by lateral compression incident to sectioning.

- 1. Optic vesicle. 3a. Profundus ganglion. 3. Quintal ganglion. 4. Acoustico-facial ganglion. 8. Vestige of anterior neuropore. 12a. First ganglionic segment; its cephalic portion. 12b. First ganglionic segment; its caudal portion. 13. Second ganglionic segment. 14. Third ganglionic segment. 15. Mesencephalon. 16. Thalamencephalon. 17. Mammillary region. 18. Infundibular region. 19. Telencephalon. 20. Ganglionic crest. 31. Pre-ganglionic segment of deuterencephalon.**

THE HISTORY OF THE

REIGN OF

CHARLES THE FIRST

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JOHN BURNET
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PLATE XXXVII

RECONSTRUCTION OF NEURAXIS OF EMBRYO OF NINETEEN SOMITES

Lateral view. Columbia Collection No. 502. $\times 210$. Reduced $\frac{1}{2}$.

1. Optic vesicle. 3*a*. Profundus ganglion. 3. Quintal ganglion. 4. Acoustico-facial ganglion. 8. Vestige of anterior neuropore. 12*a*. First ganglionic segment; its cephalic portion. 12*b*. First ganglionic segment; its caudal portion. 13*a*. Second ganglionic segment; its cephalic portion. 13*b*. Second ganglionic segment; its caudal portion. 14. Third ganglionic segment. 15. Mesencephalon. 16. Thalamencephalon. 17. Mammillary region. 18. Infundibular region. 19. Telencephalon. 20. Ganglionic crest. 24. First myelomere. 26. Velum transversum. 31. Preganglionic segment of deuterencephalon.





PLATE XXXVIII

RECONSTRUCTION OF NEURAXIS OF EMBRYO OF TWENTY-ONE SOMITES

Lateral view. Columbia Collection No. 558. Fig. 210. Reduced $\frac{1}{2}$.

1. Optic vesicle. 3*a*. Profundus ganglion. 3. Quintal ganglion. 4. Acoustico-facial ganglion. 8. Vestige of anterior neuropore. 12*a*. First ganglionic segment; its cephalic portion. 12*b*. First ganglionic segment; its caudal portion. 13*a*. Second ganglionic segment; its cephalic portion. 13*b*. Second ganglionic segment; its caudal portion. 14. Third ganglionic segment. 15. Mesencephalon. 16. Thalamencephalon. 17. Mammillary region. 18. Infundibular region. 19. Telencephalon. 20. Ganglionic crest. 22. Anterior isthmian sulcus. 23. Posterior isthmian sulcus. 27. Excrescence associated with the vestige of anterior neuropore (see page 331). 31. Pre-ganglionic segment of deuterencephalon.



PLATE XXXIX

RECONSTRUCTION OF PORTIONS OF NEURAXIS OF EMBRYOS OF EIGHT AND NINE SOMITES

FIG. 1.—Reconstruction of the cephalic extremity of the neuraxis in median section to show relief of cavity of the forebrain from an embryo of eight somites.

Columbia Collection No. 530. × 210. Reduced $\frac{1}{2}$.

1. Optic sulcus. 2. Tubercle of the floor. 7. Somatic ectoderm. 17. Mammillary region.

FIG. 2.—Reconstruction of the cephalic extremity of the neuraxis in median section to show relief of the cavity of the forebrain from an embryo of nine somites.

Columbia Collection No. 531. × 210. Reduced $\frac{1}{2}$.

1. Optic sulcus. 2. Tubercle of the floor. 7. Somatic ectoderm. 17. Mammillary region. 18. Infundibular region.

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FIG. 1

FIG. 2

PLATE XI.

RECONSTRUCTION OF PORTIONS OF NEURAXIS OF EMBRYOS OF TWELVE AND TWENTY-ONE SOMITES

FIG. 1.—Reconstruction of the cephalic extremity of the neuraxis in median section to show relief of the cavity of the forebrain from an embryo of twelve somites.

Columbia Collection No. 547. $\times 210$. Reduced $\frac{1}{2}$.

1. Optic vesicle. 2. Tubercle of the floor. 7. Somatic ectoderm. The cut surface between these two leaders is the region of adherence of the ectoderm to the neural tube. 17. Mammillary region. 18. Infundibular region.

FIG. 2.—Reconstruction of the cephalic extremity of the neuraxis in median section to show relief of the cavity of the forebrain from an embryo of twenty-one somites.

Columbia Collection No. 558. $\times 210$. Reduced $\frac{1}{2}$.

1. Optic vesicle. 2. Tubercle of the floor. 7. Somatic ectoderm. 17. Mammillary region. 18. Infundibular region.

PLATE XII

TRANSVERSE SECTION OF EMBRYO OF SIXTEEN SOMITES

**Transverse section of an embryo of sixteen somites, showing the closure of the neural tube completed prior to the appearance of the ganglionic crest.
Columbia Collection No. 551, slide 4, row 4, section 11. × 150.**

5. Neural tube. 7. Somatic ectoderm.

RECORDS OF MEETINGS
OF THE
NEW YORK ACADEMY OF SCIENCES
January to December, 1914.

BY EDMUND OTIS HOVEY, *Recording Secretary*

BUSINESS MEETING

5 JANUARY, 1914

The Academy met at 8:22 P. M. at the American Museum of Natural History, President George F. Kunz presiding.

The minutes of the last business meeting were read and approved.

The following candidates for membership in the Academy, recommended by Council, were duly elected:

ACTIVE MEMBERSHIP

F. H. Pike, Columbia University,
R. G. Eccles, 681 Tenth Street, Brooklyn,
Hermann von W. Schulte, College of Physicians and Surgeons.

The Recording Secretary then reported from the Council the recommendation that Mr. Emerson McMillin be elected a patron in recognition of his direct gifts of more than \$1,000 to the active work of the Academy.

On motion, the Academy unanimously adopted the recommendation, and Mr. McMillin was declared a patron of the Academy.

The Academy then adjourned.

EDMUND OTIS HOVEY,
Recording Secretary.

SECTION OF GEOLOGY AND MINERALOGY

5 JANUARY, 1914

Section was called to order at 8:15 P. M., Vice-President Charles P. Berkey presiding and forty-three members and guests being present.

The minutes of the previous meeting of the Section were read and approved.

The following scientific programme was then offered:

Miss Marjorie O'Connell, A REVISION OF THE GENUS *Zaphrentis*.

Chester A. Reeds, THE OÖLITES OF THE CHIMNEYHILL FORMATION OF OKLAHOMA.

Charles P. Berkey, THE ORIGIN OF SOME OF THE COMPLEX STRUCTURES OF THE ANCIENT GNEISSES OF NEW YORK.

SUMMARY OF PAPERS

Miss **O'Connell's** paper gave an account of a proposed reclassification of the genus *Zaphrentis* which will eliminate the inconsistencies at present extant.

This paper has been published as pages 177-192 of Volume XXIII of the "Annals."

Dr. **Reeds's** paper was illustrated with lantern slides showing thin sections of oörites, in which he pointed out typical structures. Hand specimens were also shown.

This paper was discussed by Professor Grabau, Dr. Berckhemmer and Dr. Berkey.

Dr. **Berkey** presented a continuation of his paper on this subject begun late last year, and this section of it was illustrated with lantern slides.

Discussion was postponed until the next meeting owing to the lack of time.

The Section then adjourned.

A. B. PACINI,
Secretary.

SECTION OF BIOLOGY

12 JANUARY, 1914

Under the auspices of the Section of Biology, a general meeting of the Academy and its Affiliated Societies was held in the main lecture hall at the American Museum of Natural History at 8:15 P. M.

President Kunz introduced the Chairman of the Section of Biology, Professor Raymond C. Osburn, who presided.

The reading of the minutes of the last meeting was dispensed with and the following programme was then offered:

CONFERENCE ON THE PILTDOWN SKULL AND THE ORIGIN OF MAN

Henry Fairfield Osborn, GEOLOGICAL AGE AND SUCCESSION OF EARLY HUMAN TYPES.

J. Leon Williams, ON THE PILTDOWN AND OTHER PREHISTORIC SKULLS.

R. Broom, CRITIQUE OF KEITH'S AND SMITH WOODWARD'S RESTORATIONS OF THE PILTDOWN SKULL.

William K. Gregory, THE BASE OF THE CRANIUM IN ANTHROPOIDS AND MAN.

SUMMARY OF PAPERS

The substance of Professor Osborn's paper will appear in Volume XXVI of the "Annals."

Dr. **Williams** gave a careful statement of the essential facts regarding the discovery of the Piltdown remains and the principal points of the reconstructions attempted by Drs. Keith and Smith Woodward.

Professor **Broom** defended Smith Woodward's reconstruction, which he held to be far better than Professor Keith's.

Dr. **Gregory** spoke in substance as follows:

Some years ago a work by the Dutch anatomist Van Kampen directed my attention to the importance of the detailed characters of the base of the brain-case as indicating the relationships of various groups of mammals. The special characteristics of the bony portions of the organs of hearing are highly significant, in revealing descent from common ancestors among widely different animals. I therefore propose to pass rapidly in review before you the basal view of the skull in many families of Primates and to point out the significance of the resemblances and differences in the auditory region.

Lemuridae. In this family the auditory bulla or bony resonating chamber of the middle ear is swollen up in a more or less hemispherical or ovoid form. It completely incloses and hides from view the delicate ring of bone upon which the tympanic membrane is stretched and which is known as the tympanic annulus or tympanic bone. The existing lemurs have evolved into widely diverse forms: here we have a more or less insectivorous form, and here a large sloth-like, leaf-eating form, and yet the formation of the auditory region is essentially identical in all. This formation is one of the characteristics which these now very diverse lemurs have probably inherited in common from remote and extinct ancestors, such as have been found in the Eocene formations of Wyoming.

1008

Indrisidæ. The *Indrisidæ* include certain highly specialized lemurs from Madagascar, such as the Sifakas and Indris. As compared with the lower lemurs great advances have been made in the structure of the teeth and in the size of the brain-case, but the formation of the auditory bulla remains the same and this is one of the characters which reveals relationship with the typical lemurs.

The *Nycticebidæ* include certain curiously modified lemuroids of Africa and the oriental region, such as the slow loris and the galagos. These lemuroids have undergone considerable modification in the basicranial region. It is much wider, the mastoid region in the back of the skull is swollen up, the tympanic annulus is no longer concealed by the bulla but lies as a short rim at the external border of the bulla.

The South American monkeys of the family *Cebidæ* differ markedly from the lemurs as follows: the tympanic annulus is not concealed by the auditory bulla but lies external to it and is closely joined with it, the suture disappearing in the young animals. The base of the brain-case has been greatly widened and the bulla itself is further in toward the mid-line than it was in the lemurs. The tympanic thus forms a short napkin-ring-like spout, called the bony auditory meatus.

The monkeys of the Old World or catarrhine Primates. In these the auditory bulla is not so much expanded as in preceding families. It is pierced by a large canal or foramen for the carotid artery. The tympanic bone now forms a greatly elongated spout leading to the outer ear. In this slide we see the wide range in structure among the existing macaques and baboons. Beginning with a short-faced more round-headed macaque we pass by almost imperceptible gradations to these very highly specialized baboons with enormous elongated faces and massive jaws and teeth. Amid all this diversity in form the structure in the auditory region remains constant, as we see by comparing the most specialized form, the mandrill, with the primitive form figured at the left.

We pass now to a much higher group of the Old World apes, the *Semnopithecinae*, which includes the langurs, the guerezas, the long-nosed monkey and others. Were it not for their high vegetarian specializations these monkeys, so far as the skull is concerned, might almost be regarded as ancestral to man. Again we have a wide variation in form from short-faced to long-faced types, but the formation and arrangement in the auditory region is the same as in all other Old World apes, namely, the bulla is not greatly inflated and is pierced by the carotid foramen or canal while the tympanic forms a long tapering spout.

The anthropoid apes all agree again in the structure of the auditory region. Here is the auditory bulla, pierced by the carotid canal, and



here is the long spout-like tympanic. Passing on the right to the human skull, notwithstanding its marked differences in the proportion of various parts, we see a fundamental agreement with the anthropoids and with all the Old World monkeys in the auditory region. Here again is the auditory bulla pierced by the carotid canal, now greatly enlarged, and here again is the long spout-like tympanic somewhat altered in external contour.

If this agreement stood by itself it might be ascribed to convergent evolution, but taken in connection with hundreds, even thousands, of other agreements it can only mean common ancestry with the anthropoids and the Old World monkeys.

The Piltdown skull fortunately preserves a portion of the auditory region together with the articulation for the lower jaw. It conforms, as do all other human skulls, to the type common to the Old World monkeys, the anthropoids and man. In the form of the articulation for the lower jaw it is very man-like, but in the form of the lower jaw itself it is more orang-like. It is thus a synthetic type combining in a way not hitherto known the characters of man and of apes.

Conclusion. If any of you may think that I have overestimated the significance of this fundamental agreement in the structure of the auditory region in man and the Old World monkeys and anthropoid apes, I can only reply that the study of evolutionary relationships is a science in itself, that by long experience the facts force themselves upon us and compel us to place certain values upon them.

The conclusion that mankind is related by common origin with the Old World monkeys and anthropoids is irresistibly forced upon palæontologists, who are familiar with scores of other well-established evolutionary series. But in view of the incredulous attitude of many it is the duty of those who are familiar with the facts to place them before the public.

The conference was followed by a collation which was served in the Eskimo Hall. The Section then adjourned.

WILLIAM K. GREGORY,
Secretary.

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY

26 JANUARY, 1914

Section met in conjunction with the American Ethnological Society at 8:15 P. M., Professor Franz Boas presiding.

The meeting was devoted to a public lecture, as follows:

Fay Cooper Cole, THE WILD TRIBES OF MINDANAO.

SUMMARY OF PAPER

Mr. **Cole** first described the Island of Mindanao and its history, then discussed in more detail the life of two of the pagan tribes—the Bukidnon and the Bagobo.

The Bukidnon, who inhabit the north-central portion of the island, have for centuries been harassed by the wild Manobo warriors on the east and by the slave-hunting Moro on the west. The many conflicts with these enemies caused them to develop a unique culture, one phase of which is shown in the tree dwellings found in part of their territory. The presence of three well marked physical types in the population is another point of interest brought out by this paper. The natives' views concerning the spirit world and some of the ceremonies made to propitiate the superior beings were described and illustrated in the talk.

Going to the Bagobo, on Davao Gulf, a glimpse was given into their traditions, laws and customs, particularly those which led up to and explained the custom of human sacrifice, and the organization known as *Magani*—the members of which gain the right to the title and a distinctive type of dress by slaying a certain number of enemies.

The lecture was illustrated by about seventy slides showing the country, the people and their homes and several native crafts.

The Section then adjourned.

R. H. LOWIE,
Secretary.

BUSINESS MEETING

2 FEBRUARY, 1914

The Academy met at 8:17 P. M. at the American Museum of Natural History, President George F. Kunz presiding.

The minutes of the last business meeting were read and approved.

The following candidates for membership in the Academy, recommended by Council, were duly elected:

ACTIVE MEMBERSHIP

W. J. Matheson, 182 Front Street,

A. A. Goldenweiser, Columbia University,

Marguerite T. Lee, 66 West 95th Street.

ASSOCIATE MEMBERSHIP

Miss Ruth Raeder, Barnard College.

The Recording Secretary then reported the following deaths:

Henry W. Boettger, Active Member since 1905, died 13 January, 1914,

Dwight A. Jones, Active Member since 1905, died 7 December, 1913,

David L. Pettigrew, Active Member since 1896, died 19 January, 1914,

George Taylor, Active Member since 1907, died 20 September, 1913.

The Academy then adjourned.

EDMUND OTIS HOVEY,
Recording Secretary.

SECTION OF GEOLOGY AND MINERALOGY

2 FEBRUARY, 1914

Section was called to order at 8:15 p. m., Vice-President Charles P. Berkey presiding.

The minutes of the last meeting of the Section were read and approved.

The following scientific programme was then offered:

Henryk Arctowski, A STUDY OF THE CHANGES IN THE DISTRIBUTION OF TEMPERATURE IN EUROPE AND NORTH AMERICA DURING THE YEARS 1900-1909.

Charles P. Berkey, ORIGIN OF SOME COMPLEX STRUCTURES OF THE ANCIENT GNEISS OF NEW YORK: IGNEOUS CONTACTS AND TRANSITIONS.

SUMMARY OF PAPERS

Dr. **Arctowski's** paper has been published as pages 39-113 of Volume XXIV of the "Annals."

Dr. **Berkey**: The following items cover the chief modifications and re-statements discussed:

The Sedimentary Series:

- 1). The fundamental formations, including the Fordham gneiss, were originally a simple sedimentary series.
- 2). There is nowhere in the region any evidence of an older basement.
- 3). The relation between the Manhattan schist and the Inwood limestone is essentially a conformable transition showing considerable oscillation and local variation.

- 4). There is also either a conformable or a simple overlap relation between the Inwood and Fordham formations with some interbedding of gneiss within the limestone.
- 5). The streaked character of the Manhattan schist is due chiefly to igneous impregnation of an already strongly foliated metamorphic rock. Its other characters are of primary sources.
- 6). The chief impurities of the Inwood, exclusive of the pegmatite dikes, are recrystallized primary matters.
- 7). The strongly banded structure of the Fordham is of complex origin—its fundamental cause is primary sedimentary difference and strong bedding structure. The rock has been injected along these weakness lines with igneous matters.
- 8). Distortions are for the most part of regional dynamic origin, but in some instances, in the larger intrusives, it is in part of flowage origin.
- 9). The prevalent granitic composition of the Fordham is in part of primary (arkose) origin and in part simple injection and in part an impregnation of granitizing solutions.
- 10). There are variations in the Fordham indicative of original interbedded limestones similar to the Inwood, and shales similar to the Manhattan, besides the more abundant sandstones and arkoses.
- 11). There is no direct evidence as to the exact geologic age and no perfectly satisfactory correlation.

The Igneous Series:

- 12). The large intrusive masses are represented by:
 - (a) "Yonkers gneiss."
 - (b) "Ravenswood granodiorite."
 - (c) "Staten Island serpentine."
- 13). The smaller igneous representatives include:
 - (d) "Pegmatite dikes."
 - (e) "Anthophyllite rock."
 - (f) "Hornblende schist strips."
 - (g) Lenticular and irregular masses and streaks of pegmatitic matter in the schists.
 - (h) Some of the bands of the Fordham gneiss.
 - (i) Much impregnating granitic matter now intimately mixed with materials of other origin.
- 14). The principal structure of the Yonkers and the Ravenswood is essentially primary and of two types:
 - (1) A superimposed structure derived from and in part preserving the structure of partially absorbed older masses.
 - (2) An induced structure due to movement in the magmatic mass during crystallization.
- 15). The structure of the hornblende schist, "Anthophyllite rock" and serpentine is chiefly secondary (metamorphic).
- 16). The igneous representatives vary in age.

- General:**

- The Section then adjourned.**

SECTION OF BIOLOGY

9 FEBRUARY, 1914

W. D. Matthew, SOME REMARKABLE EXTINCT ANIMALS OF
SOUTH AMERICA.

Robert Cushman Murphy, HABITS, ANATOMY AND RELATIONSHIPS OF
THE SEA ELEPHANT (*Mirounga leonina*).

Dr. **Matthew**: The American Museum collections of extinct South American mammals includes a series of eight mounted skeletons representing the Edentates, hoofed animals and Carnivores that flourished during the Pampæan and Santa Cruzian epochs. The chief characteristics of these animals were outlined.

Mr. **Murphy** had studied the Sea Elephants at South Georgia, a small island in the Antarctic Ocean, where he had secured a series of specimens of them and of other animals for the American Museum of Natural History and for the Brooklyn Institute of Arts and Sciences. He exhibited a remarkable series of photographs of living Sea Elephants; also a series of skulls representing the principal genera of the Phocidæ, arranged according to their structural affinities, the extremely long-skulled Sea Leopards being at the left, *Phoca*, of intermediate structure, near the center, and *Monachus* and *Mirounga*, with widened skulls, at the right.

After discussion of the papers the Section adjourned.

WILLIAM K. GREGORY,
Secretary.

SECTION OF ASTRONOMY, PHYSICS AND CHEMISTRY

16 FEBRUARY, 1914

Section met at 8:15 P. M., Vice-President Charles Baskerville presiding.

The evening was devoted to the following lecture:

H. T. Barnes, THE PHYSICAL EFFECTS PRODUCED BY ICEBERGS IN THE NORTH ATLANTIC.

SUMMARY OF PAPER

Professor **Barnes** said in abstract: The formation, drift and melting of icebergs form for the physicist subjects of inquiry of great practical value. The whole matter has been, until recently, neglected, but popular opinion now demands careful investigation of it. Although the need for such inquiry is no more acute than it has always been, the lecture now offered to the Academy deals with our present knowledge and points out the great value which would result from a careful investigation of the Labrador current, for which a large appropriation by the various governments concerned would be necessary.

The lecture was followed by a collation which was served in the Eskimo Hall. A reception was tendered to Professor Barnes, and the Section then adjourned.

E. E. SMITH,
Secretary.

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY

23 FEBRUARY, 1914

Section met in conjunction with the New York Branch of the American Psychological Association at Princeton, New Jersey, Professor R. S. Woodworth presiding.

The following programme was offered:

H. C. McComas, SOME TESTS OF EFFICIENCY IN TELEPHONE OPERATORS.

- H. A. Ruger,** TRANSFER AND INTERFERENCE IN THE SUBSTITUTION TEST.
- A. T. Poffenberger,** A COMPARISON OF THE EFFECTS OF STRYCHNINE AND CAFFEINE ON MENTAL AND MOTOR EFFICIENCY.
- H. L. Hollingworth,** A COMPARISON OF STYLUS AND KEY IN THE TAPPING TEST.
- Carl C. Brigham,** AN EXPERIMENTAL CRITIQUE OF THE BINET-SIMON SCALE.
- R. S. Woodworth,** THE WORK CURVE FOR SHORT PERIODS OF INTENSE APPLICATION.
- Garry C. Myers,** RECALL IN RELATION TO RETENTION.

SUMMARY OF PAPERS

Dr. **McComas** said: Two methods may be followed in testing telephone operators; one, by analyzing the activities at the switchboard and examining each, the other by testing these activities as a whole. The latter was followed in the work at the Princeton Laboratory. The apparatus duplicated an actual switchboard, on a small scale. The operator made connections at the board and these were timed by a kymograph in an adjoining room. The kymograph records showed the time which elapsed between the appearance of a light over a call connection and the moment an operator "plugged in;" also, between the moment a number was called and its appropriate connection made. Fifty records in succession were taken for each subject. The operators were ranked according to the quickness of their reactions. This ranking was compared with the composite ranking made by two telephone supervisors independently. The test easily detected the two best, and two out of three of the poorest, of the nine operators supplied by the Princeton exchange.

This rather difficult test was supplemented by one which called for very much simpler apparatus; practically a test in motor coördination. The operator sat before a table supporting an upright board upon which was fixed a sheet of paper containing ten crosses, arranged in three irregular rows. With a pencil she sought to touch the intersections of the crossed lines in quick succession. After each thrust at a cross the pencil point was brought down upon a blotter on the table. This gave a movement similar to that of the switchboard. Each subject was instructed to make the movements as quickly as possible, but not to sacrifice accuracy for time. Tests were made for each hand and with the sheets in various positions. The records in time were taken with a stop-watch; those for accuracy, by measuring the distances of the pencil marks from the inter-

sections of the lines. The rankings thus obtained agreed remarkably well with the estimates of the supervisors, showing a correlation of .6250, with a probable error of .14 (by Spearman's Footrule). We have, then, in this form of the motor-coördination test a valuable means of detecting the quickness and accuracy of telephone operators,—two of the most important traits which make for success at the switchboard.

In Prof. **Ruger's** paper the purpose of the study was to determine whether a well-formed rival habit or a poorly formed one had the greater influence on the formation of a given habit. The plan of the experiment included an initial and final test series with a given key and a practise series with keys formed by varying the arrangement of the test key. For the practise series the group representing the well-formed habit practised on a single rival key; the group representing the poorly formed habit either constantly changed to a new key or practised fewer times on the same rival key. In addition to these two main groups there were three control groups and one group which practised on the test key. One of the control groups read newspapers during the practise period; another did addition, and the third worked on a different type of substitution. All the groups took the initial and final tests with the test key. All the groups did better in the final than in the initial test. However, the rival-habit groups showed much less improvement than the control groups. Consequently there was a dominant interference effect. This interference effect was greater in the group that formed the one strong rival habit than in the one that formed one or many weak rival habits. The control groups were so planned as to have different degrees of relatedness in their practise series to the test keys. The newspaper group simply read what interested them—spontaneous attention; the addition group worked with voluntary attention and at top speed. The substitution-control group worked on material similar to the test series, but not conflicting with it. The three groups followed this, the above, order in the extent of the improvement of the final over the initial test. Since the difference, however, is less than the probable error, the control groups may be considered as equivalent in this particular case. The group which practised on the test keys showed two and a half times the improvement of the control groups, while the control groups showed twice the improvement of the poorly formed rival habit group and three times the improvement of the well-formed rival habit group. Improvement was measured in terms of substitutions per second.

Three hundred and fifty subjects took part in the experiment. Woodworth's and Wells's color-naming and geometrical substitution tests were employed. The symbols forming the keys were five different letters or figures.

Dr. **Poffenberger's** paper is based on a comparison of the results of two recent studies, namely, "The Influence of Caffeine on Mental and Motor Efficiency," by H. L. Hollingworth, and "The Effects of Strychnine on Mental and Motor Efficiency," by A. T. Poffenberger, Jr. Striking differences appear in the action of the two drugs upon certain mental and motor processes. The two tests were conducted on the same general plan, and comparison of the two is both permissible and easy. The tests were those well known in every psychological laboratory. Motor ability was tested by the tapping test, coördination test, and the steadiness test, while the mental ability was tested by the color-naming test, opposites test, cancellation test, and calculation tests.

Caffeine caused an increased efficiency in most of the tests, the amount of increase varying with the size of the dose. Exceptions to this statement were few, the principal one being the decrease in steadiness with the increase in the size of the dose of caffeine. No after effects were noted during the course of the test which extended over a period of about forty days.

The strychnine test, covering about the same period of time, showed none of these effects, except in the case of the steadiness test where there was a suggestion of decreased steadiness after a dose. There was neither an increase in efficiency nor a retardation measurable during the period of the test.

The explanation of the difference is to be looked for in the seat of the action of the two drugs in the nervous system, the latter acting primarily on the cord and medulla and the former affecting the higher centers of the cerebrum.

Dr. **Hollingworth** said: During a prolonged series of tests both stylus and telegraph key were used in the tapping test by the same persons. The paper presented some comparison of the results secured by the two methods. Data secured by the two methods cannot be treated as even qualitatively comparable,—the two methods not only do not yield the same results, but they do not seem even to test the same function. The key is much slower than the stylus, the difference increasing with practise. The best individual by one method is not the best by the other. There is 20 per cent. gain as the result of practise, when using the stylus, but no gain at all in the use of the key. The variability of the records is greater with the key than with the stylus. With respect to amount of improvement through practise, individuals stand in the same relative order by the two methods, but the individual variabilities are quite different in the two cases.

Mr. **Brigham** said: The Binet-Simon scale was applied to 294 children

from 6 to 16 years of age, the majority of cases (226) being under 12 years. Experimental conditions were adhered to as strictly as possible. The three investigators were always in ignorance of the physical age of the child being examined.

A normal distribution of cases about the "at age" position was found, 83 per cent. of the cases under 12 testing "at age," 3 per cent. "above age," and 14 per cent. "below age."

The scale was not uniform for all ages, as shown by the average age difference of each physical age group, given in the following array:

Physical age.....	7	8	9	10	11	12
Average difference.....	0	0	0	-0.5	-0.7	-1.4

The lack of tests above twelve years, and the difficulty of the "twelve-year" tests cause the deviations from the norm at 10, 11 and 12 years.

The teachers and the principal graded the children into five groups according to mental capacity. The average age difference of the five groups correlated with the teachers' judgments were as follows: "Very bright" + 0.9, "Bright" 0, "Average" -0.5, "Dull" -0.9, "Very dull" -1.8. In 4 per cent. of the cases there was a disagreement between the judgments of the school authorities and the results of the tests.

From the results of the investigation, it was found possible to conclude that the scale, as now standardized, measured the development of intelligence of the children examined with at least 96 per cent. efficiency, and served as an adequate measure of comparatively slight individual differences in groups of the same physical age. The "twelve-year" tests were found to be unsatisfactory. Sex differences were slight, girls possibly tending to vary more than boys. The influence of the personal equation of the experimenters upon the results of the tests was found to be negligible.

Professor **Woodworth** said: Though the question of mental fatigue has been most examined in prolonged work, it is possible that a characteristic work curve should be obtained from short periods. In collaboration with Drs. Wells and Pedrick, the author has studied periods of 5-40 seconds in controlled association tests (logical relations, color naming, simple directions), series of 10 or 20 stimuli being visually presented all at once, and the subject being required to react to the stimuli one after another without intermission. The time of each single reaction was recorded in order to see whether the speed of reaction changed in the course of the series. The work curve so obtained varies from trial to trial, but on the average runs a definite course. The initial reaction is the slowest, the next few the quickest of all, then comes a gradual decline of speed

till the last reaction, which is quicker than those just before it. In the traditional language of the work curve, we find here a rapid warming-up, followed by progressive fatigue and an end-spurt. These conceptions are, however, of questionable value when applied to so brief a period of work, and a truer interpretation may be had from the notions of overlap and interference. The "fatigue effect" is here, probably, an index of the steady accumulation of interferences, while the warming-up and end-spurt effects can be connected with the overlapping of the reactions to successive stimuli. Overlap acts to the advantage of the performance as a whole, in spite of the division of attention involved; but in the case of the first reaction, the division of attention is present without any chance of gain from the overlap, while in the final reaction the division of attention lapses and the advantage of overlap remains. When the same test material is used with an interval of a few seconds between the presentation of successive stimuli, both overlap and interference would be expected to drop out; and, in fact, the work curve under these conditions reduces practically to a dead level.

Mr. **Myers** said: Ten words were pronounced with regular tempo to 300 boys and girls of normal school, academy, seventh and eighth grades. The subjects were made to believe it was a regular spelling test. At various intervals the several groups of each grade were surprised by the request to recall as many of the words as they could remember. All groups compared gave a final recall after the same interval (one hour, one-half hour, or three weeks). One group had two intervening recalls, one had one and one had no intervening recalls.

The results for final recall are best with two intervening recalls, and for one intervening recall much better than for none. The gain by the five minute over the immediate recall is noticeably greater in its effect on the final recall than the gain of immediate recall over no intervening recalls. The total percentages for the respective groups of girls are 89, 71, 58; for the boys, 73, 61, 52 (final recall after 30 minutes). The total percentages show a strong gain in efficiency in the final recall after one hour, as a result of immediate recall—girls, 76, 43; boys, 61, 40.

On the whole the girls are noticeably superior to the boys and their mode is one degree higher for each period of time. For immediate recall and recall after one hour the mode for the boys is at 5, for the girls, at 6. After three weeks it is at 4 and 6, respectively. The average deviation from the mode is consistently greater for the girls than for the boys.

The pedagogical significance of these findings, especially in relation to drill and frequent reviews, is obvious.

(This paper is published in full in the "Journal of Educational Psychology," March, 1914.)

The Section then adjourned.

R. H. LOWIE,
Secretary.

BUSINESS MEETING

2 MARCH, 1914

The Academy met at 8:15 p. m. at the American Museum of Natural History, President George F. Kunz presiding.

The minutes of the last business meeting were read and approved.

The following candidate for active membership in the Academy was duly elected:

Harvey Deschere, 50 Church Street.

The Recording Secretary reported the transferal of T. C. Brown from the associate membership to the active membership list; and the following death:

Mrs. C. T. Olmsted, Active Member of the Academy since 1907, died 21 January, 1914.

The Recording Secretary stated to the Academy that progress was being made on the Porto Rico Survey and read the report made to the Committee by Professor H. E. Crampton of his reconnaissance visit to the Island, 27 December, 1913, to 31 January, 1914.

The Academy then adjourned.

EDMUND OTIS HOVEY,
Recording Secretary.

SECTION OF GEOLOGY AND MINERALOGY

2 MARCH, 1914

Section was called to order at 8:15 p. m., Vice-President Charles P. Berkey presiding.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

Francis M. Van Tuyl, THE ORIGIN OF DOLOMITES.

Douglas W. Johnson, THE STABILITY OF THE ATLANTIC COAST.

SUMMARY OF PAPER

Mr. **Van Tuyl** summarized briefly the existing theories of the origin of dolomite and pointed out that the experimental evidence was at present

not adequate to predict the conditions under which this rock is formed in nature.

The field studies furnish irrefutable evidence that the majority of the dolomites examined have resulted from the alteration of limestone. This evidence consists of the lateral gradation of layers of dolomite into limestone, sometimes very abruptly; the mottling of limestone by irregular patches of dolomite; the existence of remnants of unaltered limestone in masses of dolomite; the irregular boundary between beds of limestone and of dolomite; the presence of altered oölites in some dolomites; the protective effect of shale beds; and the obliteration of structures. The conclusion was reached that the alteration must have proceeded in most cases while the limestone was still beneath the sea, but it was admitted that ground water was capable of producing local dolomitization under favorable conditions after emergence.

The Section then adjourned.

A. B. PACINI,
Secretary.

SECTION OF BIOLOGY

9 MARCH, 1914

Section met at 8:15 p. m., Professor Raymond C. Osburn presiding.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

G. S. Huntington, THE ILIO-COLIC JUNCTION IN VERTEBRATES FROM
THE STANDPOINT OF TAXONOMY AND FUNCTION.

H. von W. Schulte, THE DEVELOPMENT AND ANATOMY OF THE SALI-
VARY GLANDS IN CERTAIN MAMMALIAN ORDERS.

SUMMARY OF PAPERS

Professor **Huntington** gave a review of the more important results which had been based on the study of an extensive series of anatomical preparations of the ilio-colic region in representative vertebrates, in the College of Physicians and Surgeons. He discussed the relation of form and function and the several homologies of the parts of the ilio-colic region in many fishes, amphibians, reptiles, birds and mammals.

Professor **Schulte's** paper summarized the investigations of Drs. Huntington, Schulte and Carmalt, published by the Columbia University Press, 1913 (Vol. IV of Studies in Cancer and Allied Subjects Conducted under the George Crocker Special Research Fund at Columbia University).

After discussion of the papers by Professor R. C. Osburn and others the Section adjourned.

WILLIAM K. GREGORY,
Secretary.

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY

23 MARCH, 1914

Section met in conjunction with the American Ethnological Society at 8:15 P. M. The meeting was opened by Dr. George F. Kunz, President of the Academy, who introduced Dr. Robert H. Lowie, sectional secretary, as the chairman of the meeting.

Dr. Lowie then introduced Professor Hiram Bingham of Yale University, the lecturer of the evening, the programme being

Hiram Bingham, RECENT EXPLORATION IN THE LAND OF THE INCAS.

SUMMARY OF PAPER

Professor **Bingham's** lecture gave the results of the expedition of 1912 under the joint auspices of Yale University and the National Geographic Society, which had for one of its chief objects the clearing and exploration of Machu Picchu, in southern Peru, a city so ancient that there is no reference to it in the Spanish chronicles, and its old name is not known. The ruins were discovered by the Yale Expedition of 1911.

This ancient city, which seems to have been built by the Incas or their immediate predecessors, between one and two thousand years ago, is situated on a narrow, precipitous ridge 2,000 feet above the Urubamba River. It is 9,000 feet above the sea, and is located in one of the most inaccessible parts of the Andes, about 60 miles north of Cuzco. It contains about 200 edifices, including palaces, stairways, temples, fortifications, and shrines, all built out of white granite. It is admirably situated for defense, and is protected by two walls and a dry moat. In culture it is probably purely Incaic. Owing to the extraordinary number of windows, the presence of three large windows in the principal temple and the evidence of the city being finely situated for a place of refuge, it is thought that possibly we may have here the ancient "Tamp Tocco," which is ordinarily supposed to have been south of Cuzco, near the village of Peccaritampu.

The lecture was illustrated with lantern slides.

After the address, a collation was served in the Eskimo Hall. This

was followed by a reception to Professor Bingham, and the Section then adjourned.

R. H. LOWIE,
Secretary.

BUSINESS MEETING

6 APRIL, 1914

The Academy met at 8:15 P. M. at the American Museum of Natural History, President George F. Kunz presiding.

In the absence of Dr. Hovey, Professor Berkey was appointed Secretary *pro tem*.

The minutes of the last business meeting were read and approved.

The following candidates for membership in the Academy, recommended by Council, were duly elected:

ACTIVE MEMBERSHIP

B. A. Hayner, Washington Irving High School,
E. B. Slack, Washington Irving High School,
S. S. Bernstein, Catskill Board of Water Supply.

ASSOCIATE MEMBERSHIP

Y. Tsenshan Wang, Department of Geology, Columbia Univ.

The Secretary reported the death on 16 March of Sir John Murray, Honorary Member of the Academy, and read the following cablegram sent to his family and the acknowledgment thereof:

"MURRAY, *Challenger Lodge,*
Wardie, Edinburgh, Scotland:

New York Academy of Sciences expresses its deep sorrow over loss to science through death its honorary member Sir John Murray and its heartfelt sympathy with surviving family.

(Signed)

EDMUND OTIS HOVEY, *Secretary.*"

CHALLENGER LODGE, WARDIE, EDINBURGH.

"Dr. HOVEY,

Secretary, New York Academy of Sciences.

DEAR SIR: I am desired by Lady Murray and family to offer to you, and through you to the members of your Academy, their heartfelt thanks for your kind message of sympathy.

With the expression of my profound respect, I am, Dear Sir,

Yours faithfully,

(Signed)

JAMES CHUMLEY, *Sec'y.*"

The Secretary reported that in response to an invitation from the president of the Circolo Matematico di Palermo the Council had appointed the Marquis Antonio de Gregorio, Corresponding Member, to represent the Academy at the thirtieth anniversary of the foundation of the Circolo, to be held on 14 April.

The Secretary reported that Professor N. L. Britton, Chairman of the Committee on the Natural History Survey of Porto Rico, had received from the Commissioner of Education of Porto Rico a cablegram to the effect that the legislature had approved the budget for the next fiscal year, including an item of \$5,000 for the purposes of the Academy's Natural History Survey, also that Professor Britton had received from Major Basil Dutcher, a letter conveying the same information and saying that the government's appropriations become available 1 July. The expectation is that this appropriation is to be repeated each year for an additional four years in accordance with the proposition made by the Academy.

The Academy then adjourned.

CHARLES P. BERKEY,
Secretary pro tem.

SECTION OF GEOLOGY AND MINERALOGY

6 APRIL, 1914

Section was called to order, Vice-President C. P. Berkey presiding. In the absence of the Secretary, Dr. R. B. Earle was chosen to act as secretary *pro tem.*

The following programme was offered:

George Frederick Kunz, THE JOHN BOYD THACHER PARK; THE
HELDERBERG ESCARPMENT.

Charles P. Berkey, ORIGIN OF SOME OF THE COMPLEX STRUCTURES OF THE ANCIENT GNEISSES OF NEW YORK:—IGNEOUS *versus* RECRYSTALLIZATION EFFECTS.

Alexis A. Julien, THE GENESIS OF ANTIGORITE AND TALC.
D. S. Martin, A PECULIAR FORM OF RADIATED TOURMALINE FROM VIRGINIA.

SUMMARY OF PAPERS

Dr. **Kunz** presented a paper on the Helderberg Escarpment as shown at Countrymen Hill Station—The John Boyd Thacher Park.

On suggestion of Professor J. F. Kemp, the chairman appointed a committee of three, Prof. Kemp, Dr. Pacini and Dr. Earle, to draw up and send to Mrs. Thacher resolutions expressing the thanks and appreciation of the Section of Geology of the New York Academy of Sciences for the gift of the John Boyd Thacher Park.

Dr. **Berkey**, in his paper, covered the sedimentary series and the igneous series and concluded as follows:

As a result all of the formations are complex in composition—in part primary, in part metamorphic, in part introduced and all the formations are also complex in structure—in part of primary sedimentary control, in part induced by metamorphism (recrystallization), in part of primary igneous habit, in part a primary structure emphasized by its control over igneous injections, and in part a purely secondary dynamic effect.

This paper was illustrated with lantern slides and was followed by a discussion by Prof. Kemp, Dr. Kunz, Dr. Reeds, Dr. Earle and Mr. Hawkins.

Prof. **Kemp** presented in brief summary the paper by **Alexis A. Julien** as follows: Conclusions in this paper are that magnesia, in hydrated or carbonated condition, and deweylite and sepiolite in colloid form, have always been the only magnesian derivatives from laterite, with tendency to early migration and transport, in virtue of their solubility.

Antigorite and talc, crystalline and never colloid, have merely served as insoluble fixatives to harden and record the transformations of their mobile and protean predecessors.

Chrysolite is but a pseudo-fibrous variety of antigorite in fact, a pseudomorph in antigorite after a pseudomorph in deweylite after nemo-lite, the fibrous form of brucite.

To the list of rock-making minerals, brucite, deweylite and sepiolite need to be added as important accessories.

This paper has been published as pages 23-38 of this volume.

Dr. R. B. Earle read a short paper by **D. S. Martin** as follows:

Some time ago I received from Mr. John H. Porter of Brooklyn, N. Y., a number of minerals from Nelson County, Virginia, where he had been engaged in prospecting and mining for some time. Among these were several specimens of black tourmaline which presented some features that to me were novel and peculiar. I asked Mr. Porter if he could obtain any more examples of this form, and have recently received some from him.

The specimens at first sight present simply the aspect of rather weathered nodules of solid tourmaline the average size of hickory nuts. Many of them are irregular in form but all show a distinctly radiating

structure. In the larger and more characteristic specimens, the curious combination appears of a radiated nodule with a distinct general crystalline form. The nodules are seen to be pyramidal in shape and subtriangular in outline, expanding to a convex base or termination which shows distinctly in many cases not a mere spherical convexity but the characteristic low rhombohedral termination so familiar in tourmaline crystals. This peculiar combination is unknown to me from any other locality, and has seemed worthy of special notice. I presented a description with specimens before the New York Mineralogical Club at its meeting in November last, and now desire that it be laid before the Academy.

These crystalline nodules are single developments, not fragments from spherical masses, as might at first be supposed from their pyramidal form; but the termination is entirely too convex for this supposition. I regret very much that I do not know exactly their mode of occurrence. They are found loosely scattered through the soil and probably come from gneisses or mica schists at a greater depth, but no specimens have reached me that show any portion of attached matrix. Professor Watson, the State Geologist of Virginia, inclines to the view that they are derived from pegmatites; but he has not seen the specimens themselves and has no positive evidence. Their mode of occurrence is one that is extremely familiar in the south where the country rock is weathered and decomposed sometimes to great depths, forming the surface mantle of so-called "southern drift," in which are distributed the harder and more resistant minerals that have been liberated in the decay of the matrix.

Most of the specimens which I obtained from Mr. Porter have been placed, together with all my other southern material, in the "Piedmont Collection" of minerals of the South Atlantic states which I am engaged in forming at the Charleston (S. C.) Museum; but I furnished Mr. Gratacap of the American Museum at New York with a few characteristic examples.

The precise locality of these specimens as given by Mr. Porter is Tye River, Nelson County, Va.

This peculiar form, a radiating nodule, possessing also the triangular contour and the rhombohedral termination of a tourmaline crystal is, so far as I know, peculiar to this locality, and I have deemed it worthy of special description.

The Section then adjourned.

R. B. EARLE.

Secretary pro tem.

SECTION OF BIOLOGY

13 APRIL, 1914

Section met at 8:15 p. m., Professor Raymond C. Osburn presiding. The minutes of the last meeting of the Section were read and approved. The following programme was then offered:

SYMPOSIUM ON PORTO RICO

- James F. Kemp,** GEOGRAPHY AND GEOLOGY.
Charles Lane Poor, OCEANOGRAPHY.
Henry E. Crampton, ZOÖLOGY (including results of expedition of December, 1913-January, 1914).
N. L. Britton, BOTANY (including results of expedition of January-February, 1914).

SUMMARY OF PAPERS

Dr. **E. O. Hovey** outlined the plans for a Natural History Survey of Porto Rico, which had been adopted by the Council of the Academy, under the leadership and with the patronage of President McMillin.

Professor **Kemp** summarized existing knowledge of the topography and geology of Porto Rico and indicated the need for further field studies.

Professor **Poor** spoke of the strategic importance of the seas around Porto Rico in certain oceanographic problems, such as the place of origin and movements of the tides of the Atlantic and their relationships with the tides of other ocean basins; and he urged the desirability of equipping an oceanographic expedition for securing data bearing on such problems.

Professor **Crampton** described his recent journey in Porto Rico. In the course of a general reconnaissance of the island in the month of December, 1913, he had covered some 1,500 miles, traversing the principal physiographical and ecological areas, the characteristics of which he described, and thus learning the places where detailed natural history surveys could be most profitably undertaken.

Professor **Britton** spoke of his recent visit to the island and illustrated characteristic elements of the flora.

The Section then adjourned.

WILLIAM K. GREGORY,
Secretary.

SECTION OF ASTRONOMY, PHYSICS AND CHEMISTRY

20 APRIL, 1914

Section was called to order at 8:15 p. m., Vice-President Charles Baskerville presiding.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

Victor S. Meyers, CREATINE AND CREATININE.

Morris S. Fine, URIC ACID.

SUMMARY OF PAPERS

Professor **Meyers's** paper has been published in "The Post-Graduate" for June, 1914.

Dr. **Fine's** paper has been published in "The Post-Graduate" for July, 1914.

A discussion by Drs. Howe and Smith and Professor Baskerville followed the presentation of the papers.

The Section then adjourned.

E. E. SMITH,
Secretary.

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY

27 APRIL, 1914

Section met in conjunction with the New York Branch of the American Psychological Association at Columbia University, Professor R. S. Woodworth presiding.

The following programme was offered:

Miss Estelle De Young,	IS THERE SUCH A THING AS GENERAL INGENUITY?
Garry C. Myers,	A STUDY OF APPETITE.
Miss Edith F. Mulhall,	EQUIVALENCE OF REPETITIONS FOR RE- CALL AND RECOGNITION.
W. S. Monroe,	STUDIES IN RECOGNITION.
Miss Laura Watson Benedict,	A STUDY OF BAGOBO CEREMONIALS, Magic and Myth. (Read by Title.)
Miss Mary Ross,	IS THERE SUCH A THING AS GENERAL JUDICIAL CAPACITY?

Miss Lillian Walton,	INDIVIDUAL DIFFERENCES IN JUDICIAL CAPACITY.
Max G. Schlapp,	SOME ETIOLOGICAL FACTORS OF MEN- TAL DEFICIENCY.
H. A. Ruger,	SEX DIFFERENCES IN THE SOLUTION OF MECHANICAL PUZZLES.

SUMMARY OF PAPERS

Miss **De Young** said: Various psychologists have attempted to prove the existence of definite relations between different mental abilities. The problem suggested itself: Is there such a thing as general ingenuity? Our definite purpose was to select tests having a common element, ingenuity; and to find whether in such a series ability to solve one problem necessarily means ability to solve another.

By ingenuity we mean the use of judgment, logical thought, selection from a mass of material suggested by the problem, and a skill and quickness in manipulating and forming new combinations of possible means for solution.

We presented nine problems to a group of 25 Barnard students. They were in order: (1) a mathematical problem; (2) a test for forming words from the letters in the word "psychiatry" for which five minutes were allowed; (3) a test, which for convenience we called the "limerick," adding two lines of poetry to complete two lines presented; (4) ten syllogisms to be marked either valid or invalid; (5) an original poem of from four to six lines; (6) the absurdity test, or the marking of the absurd sentences in a list; (7) directions; (8) mechanical puzzle, and (9) a puzzle for which thirty minutes was the time limit.

For each individual the score for mathematics consisted of two columns, the time and correctness or incorrectness of the solution; for test 2 the number of words formed; for tests 3 and 5, both the time and order of merit of the poetry; for the syllogisms, the time and the per cent. of correct judgments; for the absurdity and directions the time and number of errors; for the mechanical puzzle only the time, and for the ingenuity, either the time, or if not solved within thirty minutes, the failure.

In every single column the order of merit of the 25 subjects was determined. Where the test consisted of two columns, the order of merit of each individual was averaged so that every test had only one column determining the order of merit of the subject in that ability. The differences in merit for each individual were obtained by comparing each test with every other test.

The results were then obtained by averaging the figures in each of the thirty-six columns and the correlations between the different abilities found by the method of rank differences.

The correlations run as high as .788 for limerick and absurdity; .737 for limerick and directions, and decrease very gradually to three negative correlations which are almost zero: namely, $-.032$ for words and mechanical puzzle; $-.062$ for mathematics and ingenuity and $-.160$ for mechanical and ingenuity.

The following are the correlations of each test with the other eight tests:

Limerick .....	.629
Poem .....	.575
Directions .....	.525
Absurdity .....	.499
Logic .....	.493
Words .....	.366
Mathematics .....	.325
Ingenuity .....	.285
Mechanical puzzle.....	.210

The limerick and poem lead. Mathematics stands low in the scale as a representative of ingenious capacity and probably involves a relatively independent trait. The mechanical and ingenuity puzzles on account of their concreteness are not so likely to correlate well with the other tests, which involve mostly ideational processes.

Mr. Myers continued a study of appetite which was begun by one of his pupils of Juniata College, Miss Margaret Baker. Her questionnaire which she applied to 75 students was extended by the writer to other subjects of college, normal school and high-school grade, making a total of 483 subjects—258 boys and 225 girls. From the twenty foremost likes and the twenty leading dislikes secured by the questionnaire the names of forty things to eat were printed on slips of paper, shuffled, and presented to each of fifty men and fifty women who were asked to rank the forty things in the order in which they were liked, and to indicate, in case any were disliked, where the dislikes began. Three weeks after the first test the same subjects were surprised by the request to arrange again the items in the order in which they were liked after the manner of the first test.

With 25 of the items another random list was selected and with it 50 boys and 50 girls of the high school and the same number of boys and girls in the grammar schools of Tyrone, Pennsylvania, were tested. As with the college students, a second record after three weeks was obtained.

Only a part of the results of the college subjects were reported. It was

found, on the whole, that the results of these tests followed the general order of preference indicated by the results of the questionnaire. Noticeable sex differences obtained in the order of preferences. For example, eggs, which stood first with the men was ranked by the women as sixth; milk stood fourth with the men and twenty-second with the women; salads, twenty-second with the men and fifth with the women; cucumbers, thirty-sixth (fourth from the last) with the men and nineteenth by the women.

The correlation between the median performance of the first and second tests was .96 (Spearman's footrule). The average P.E. of the first performance (average for all items) was 6.50; for the second 7.04.

The individual correlations or indices of consistency ranged from .96 to —.05 with a median at .84 (P.E. 8.00). The second lowest, however, was .39 and third .51. The subjects were most consistent in the arrangement of their foremost likes (first five). For the last five the arrangement was likewise more consistent than for the average, but not so consistent as for the first five.

The median number of items disliked by 50 men was for the first test 7.70 (P.E. 2.79) and for the second test 9.00 (P.E. 4.00). By the 50 girls the corresponding figures were 8.50 (P.E. 3.07) and 8.83 (P.E. 2.83).

Miss **Mulhall** said: The present investigation was to study the equivalence of repetitions for recall and recognition for four materials, pictures of objects, geometrical forms, words, and nonsense syllables. Each subject was shown 15 words successively at intervals of two seconds each and then required to reproduce those he remembered in three minutes. The subject was then given a set of 30, containing the original 15 words, from which he was to select 15 which he thought were previously presented. The first set of 15 words was shown again as before, and then the subject requested to recall those he could and select 15 from the 30 set. This was continued until he had recognized and recalled all of the 15 words correctly. The experiment was repeated for the three other materials (forms, syllables and pictures).

The results show that the difference between recall and recognition is greatest for pictures, somewhat less for forms and words and least for nonsense syllables. In examining the material one finds the pictures offer the greatest richness of associations. The forms, too, can be visualized and in several cases named; the words, which were all nouns, have some associations, but lack a form or picture element. The syllables, as their name implies, were nonsense, most, if not all, of which were devoid of any association.

The individual differences shown by the subjects are rather interesting. The ratio of the greatest number of repetitions to the least number increases as we pass from the pictures to the forms, words and finally to the syllables for recognition and for recall with the exception of syllables.

From the experiment it may be concluded that the difference between recall and recognition varies with the material to be remembered. The greater the wealth of association offered by the material the greater the difference between recall and recognition. It is suggestive, at least, that individual differences, especially in recognition, are least when the material is rich with associations and increase as the material has fewer associations.

One of the practical applications is in the selection of trade-marks. To be successful a trade-mark should be easily recalled and recognized. Arbitrary combinations of letters, like the nonsense syllable, must be presented many more times than pictures or forms, and yet we find the business firms are continually using nonsense material as trade-marks.

Miss **Ross** said: Judging in general is a thing about which we all speak with much assurance. In fact, we hardly ever pick up a paper without seeing an advertisement for a person of "good judgment." However, if we should turn to psychology to see what the psychologists have said about a general capacity of judgment we should find practically nothing. James is the only one who has much to say on the subject and his words are little more than a suggestion for further investigation. It was to determine if there is any general judicial capacity and to find if there is any correlation between different kinds of judgments that this experiment was performed.

The material was of six kinds, involving judgments of art, rhythm, tact, punishments, expenditure of salary and an ethical judgment. The results proved that we had a social group of subjects, as the highest ratio was 65 per cent., and the lowest 32 per cent., carrying out the two-to-one ratio which usually characterizes a social group.

The individual percentages were obtained by having the subjects arrange the material by the order of merit method. Then we obtained the average order of the group and used this as a standard. We correlated the arrangement of each individual with the standard arrangement, and the resulting per cent. shows the degree to which the individual is correlated with the group.

When we had secured these results, we correlated the results of the different groups and found that there is no relation between them. The average of the correlation is $-.09$. That is, if a person, for instance, is a good judge of rhythm, we might expect him to be an equally good

judge of tact, but the chances of this being true are negative. It is the same in any two things you choose; the correlation is practically zero.

Thus we may conclude that, whereas certain persons are endowed with better judgment than others, there is nothing that can be pigeon-holed as general judicial capacity, and the fact that a person is good in different kinds of judgment is due to chance only, not to any intercausal relation. There is no correlation whatsoever between the different types of judgment. The highest per cent. obtained by any one in the judgment of ethics was 93 per cent., yet that same person was $-.28$ per cent. in artistic judgment; so we can safely say that there is no general judicial capacity, nor is there any correlation between the different kinds of judgment.

Miss **Walton** said: The material for this experiment consisted of a series of fifteen possible reactions to a given stimulus. These were typewritten on strips of cardboard of approximately uniform size. The subjects were instructed to arrange the material in order of merit with regard to their rhythmical, ethical, practical, tactful, or artistic value.

The material for rhythmical judgment consisted of short stanzas, selected from various poets, ranging from Milton to Kipling; that for artistic judgment of small reprints from various celebrated artists. The practical judgments included a series of budgets prepared for the expenditure of a school-teacher's salary, and a list of punishments for the trivial offenses of a small child.

From the arrangements made by the twenty-five subjects, we estimated the average order. Then we determined the degree of correlation between the average and the individual orders.

From these statistics, we found that, in the subjects studied there is a greater agreement in ethical judgment than in any other kind. The judgment of art proved to be the poorest, the average correlation with the average judgment being $+.68$ and $+.41$, respectively. Next in order to the ethical judgment came the judgment of budgets with an average of $+.63$.

Arranged in numerical order, the averages for the various judgments were: ethical, $.68$; practical (budgets), $.63$; tact, $.62$; practical (punishments), $.48$; rhythmical, $.42$; artistic, $.41$.

This would seem to suggest that people, in general, judge most nearly alike on matters which are of general interest and differ most on matters which are purely personal.

The individuals in the group differed greatly among themselves. In the average for the various materials, they ranged from 36 per cent. correlation with the average to 16 per cent.

We found no sex differences among our subjects. Since there were only five men and twenty women, our results can only be suggestive, but, in this investigation, the women differed more among themselves than they did from the men. For example, a group of five women school-teachers differed more from a group of five women students than the whole group of women, or any separate group of them, differed from the men.

It was also interesting to note that the group of five women school-teachers had a very much higher correlation with the group, as a whole, on the subject of the practicability of the budgets prepared for a school-teacher's salary than the rest of the group.

Another point suggested by this experiment is the fact that individuals whose average correlation differed within a very small range had a very much higher general average than those individuals who differed over a very wide range.

Another interesting fact was that those individuals who had the lowest correlation for the judgment of punishments were, in almost every case, people who had had no experience in punishing.

We also found that those individuals who had the highest average were, approximately, the oldest people in the group, whereas those who had the lowest average were about the youngest. These facts suggest that judgment is a matter of practice.

The facts, as here presented, seem to suggest a negative correlation between practical and artistic judgment.

Professor **Ruger**: A series of fifteen puzzles, fourteen of which formed a related series involving the same principle, but with increasing complexities, was given to 55 students (30 women and 25 men) in the mechanical drawing classes of Teachers College, and to 23 students (15 women and 8 men) taking an advanced course in mathematics. Thirty minutes were allowed for the test. On the present method of scoring, each puzzle was counted as having a value of 1. As a matter of fact the later numbers were more difficult than the earlier. Weighting the later members would probably enhance the differences to be stated. In the group of 55 students $6\frac{2}{3}$ per cent. of the women reached the rank of the median man. In the case of the mathematics group 20 per cent. of the women reached the rank of the median man.

A single puzzle was tried with three other groups of students, chiefly in elementary and secondary education. In group *A*, 5 men and 21 women, 29 per cent. of the women reached or exceeded the position of the median man. In group *B*, 8 men and 22 women, 9 per cent. of the women reached the position of the median man. In group *C*, 6 men and

25 women, 33 per cent. of the women reached the position of the median man. Group *A* learned the puzzle after being given the theory for it; group *B* unaided, and group *C* by imitation. What part of the actual difference is a true sex difference is not determined.

The Section then adjourned.

ROBERT H. LOWIE,
Secretary.

BUSINESS MEETING

4 MAY. 1914

The Academy met at 8:17 P. M. at the American Museum of Natural History, President George F. Kunz presiding.

The minutes of the last business meeting were read and approved.

The following candidate for active membership in the Academy, recommended by Council, was duly elected:

James Loring Arnold, New York University.

The Recording Secretary reported the following deaths:

Charles J. Perry, Active Member of the Academy since 1905, died
13 July, 1913,

Karl Hutter, Life Member of the Academy since 1910, died 14
June, 1913.

The Academy then adjourned.

EDMUND OTIS HOVEY,
Recording Secretary.

SECTION OF GEOLOGY AND MINERALOGY

4 MAY, 1914

Section was called to order by Vice-President C. P. Berkey. In the absence of the Secretary, Professor D. W. Johnson was appointed secretary *pro tem*. The meeting was favored with the presence of the State Paleontologist, Dr. John M. Clarke. About 40 members and visitors were in attendance.

Dr. George F. Kunz reported briefly upon the nature of a large collection of diamonds from the Transvaal which he had recently examined.

The Section then proceeded to the regular programme of the evening as follows:

Fritz Berckhemmer,

ON THE OCCURRENCE OF CALCAREOUS
ALGÆ IN THE PALEOZOIC ROCKS OF
NORTH AMERICA.

Francis M. Van Tuyl and

Fritz Berckhemmer, A PROBLEMATIC FOSSIL FROM THE CATSKILL FORMATION.

Francis M. Van Tuyl, THE MOTTLED TRIBES HILL LIMESTONE AND ITS BEARING ON THE ORIGIN OF DOLOMITE.

A. W. Grabau, THE BLACK SHALE PROBLEM: A STUDY IN PALEOZOIC GEOGRAPHY.

SUMMARY OF PAPERS

Dr. **Berckhemmer** showed by means of lantern slides the presence of the genus *Sphærocodium* in Ordovician rocks of this country, a matter of unusual interest because it constitutes the earliest known occurrence of this genus. A new species of calcareous algæ from the Upper Ordovician was described, and pictures of the first known lime-precipitating algæ from the North American Silurian were exhibited.

The paper was discussed by Dr. J. M. Clarke and Dr. E. O. Hovey.

Mr. **Van Tuyl** read his joint paper with Dr. Berckhemmer. He described and discussed a fossil of uncertain affinities, collected from the Catskill beds at Henrysville, Pennsylvania. The authors concluded that the form could not safely be referred to any known groups of organisms.

Dr. Clarke and Professor Grabau discussed the paper briefly.

Mr. **Van Tuyl**, in his paper on limestone, showed that the mottled structure of this limestone was due to the presence of irregular patches of yellowish, coarse-grained dolomite, which stand out in relief on weathered surfaces. The dolomitization proceeded either in an irregular and imperfect manner by alteration along stratification lines or in disconnected patches; or in a more regular manner along definite lines which appear to represent worm castings. In both types of alteration, certain layers of the limestone have locally been completely changed to dolomite. It was concluded that the mottled limestone represented an incomplete stage in the process of dolomitization, and that the alteration had taken place at the time of, or very shortly after, deposition.

The paper was discussed by Dr. Clarke and Professor Berkey.

Dr. **Grabau** indicated, with the aid of maps and diagrams, probable physiographic conditions which existed when the black shale was deposited. Various theories which have been proposed to explain this formation were briefly outlined and criticized. The author concluded that the shale represented fine black soil of a low-lying peneplain which was in part washed into the sea by rivers, and in part reworked by waves and currents as the sea transgressed the land. In the northern sections the

shale is believed to be of Devonian age, while farther south it is Mississippian.

Dr. Clarke briefly indicated a number of points on which he disagreed with the author's conclusions. The paper was further discussed by Mr. F. W. James.

The Section then adjourned.

D. W. JOHNSON,
Secretary pro tem.

SECTION OF BIOLOGY

11 MAY, 1914

Section met at 8:15 P. M., Professor Raymond C. Osburn presiding. The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

H. von W. Schulte, EARLY STAGES IN THE DEVELOPMENT OF THE
BRAIN IN THE DOMESTIC CAT.

Frederick Tilney, THE MORPHOLOGY OF THE FLOOR OF THE THIRD
VENTRICLE IN CRANIATES.

O. S. Strong, THE THEORY OF NERVE COMPONENTS.

SUMMARY OF PAPERS

Professor **Schulte** discussed the very early and hitherto little known stages in the development of the brain in the domestic cat in their bearing on the problem of the primary encephalic segments of the mammalian brain. This paper has been published as pages 319-346 of this volume.

Dr. **Tilney**, by means of a series of cross-sections and reconstructions of the region of the hypophysis in typical vertebrates, endeavored to trace the homologies of the diversely modified parts throughout the vertebrate series. (Partly published in "Internat. Monatsschrift für Anat. und Physiol." Bd. XXX, 1913.)

Dr. **Strong** traced the history of his subject especially in relation to the work of the "American school" of neurologists. He discussed the morphological classification of nerves and nerve components, spoke of the technique of tracing nerve components in complex bundles and outlined the broader conclusions relating to the several homologies of the cranial nerves in fishes on the one hand and in terrestrial vertebrates on the other.

After remarks by Professor Huntington and others the Section adjourned.

WILLIAM K. GREGORY,
Secretary.

SECTION OF ASTRONOMY, PHYSICS AND CHEMISTRY

18 MAY, 1914

Section was called to order at 8:15 P. M., Vice-President Charles Baskerville presiding.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

D. D. Van Slyke, THE MECHANISM OF ENZYME ACTION.

Victor E. Levine, BIOCHEMICAL STUDIES OF SELENIUM.

SUMMARY OF PAPER

Dr. **Levine** said in abstract: Experiments were reported relating to the reduction of selenium compounds of chemical substances of biologic significance, by micro-organisms, by plant and by animal tissues. Toxicological and pharmacological effects were also studied, as well as the effect on germination and growth of plants, the effect on enzyme activity and the effect on the precipitation of proteins. The compounds employed were selenium dioxide (selenious acid), sodium hydrogen selenite, normal sodium selenite, selenic acid, sodium selenate, potassium selenocyanate.

A discussion took place after the presentation of the papers.

The Section then adjourned.

E. E. SMITH,
Secretary.

BUSINESS MEETING

5 OCTOBER, 1914

The Academy met at 8:19 P. M. at the American Museum of Natural History, President George F. Kunz presiding.

The minutes of the last business meeting were read and approved.

The following candidate for Associate Membership in the Academy, recommended by Council, was duly elected:

Warren S. Smith, Columbia University.

The Recording Secretary reported the following deaths:

Heinrich Rosenbusch, Honorary Member since 1887, died 20 January, 1914,

Seth Eugene Meek, Correspondent since 1888, died 6 July 1914,

A. S. Bickmore, Fellow and Active Member since 1873, died 13 August, 1914,

Samuel H. Bishop, Active Member since 1907, died 30 May, 1914,
J. Langeloth, Active Member since 1905, died 14 August, 1914.

Dr. **Kunz** presented a note regarding the long period of dry weather in eastern North America, an abstract of which is as follows:

Realizing that we have had no rain since the first of August, except a few showers, a possible solution presents itself. We all know that it is believed that the bursting of high explosives precipitates moisture; the evening of the Fourth of July, when fireworks are used, generally ends in a shower. We know, furthermore, that all northern Europe has recently suffered intensely from rains of unusual severity, causing loss of life and difficulty in transporting heavy artillery, and that these atmospheric conditions have followed the bursting of innumerable shells over a wide range of territory in this region.

Is it possible that the absence of equinoctial storms in this country may be indirectly the result of the constant and prolonged use of explosives in the war in Europe? Through the courtesy of Mr. Spur, Director of the New York office of the Weather Bureau, it is shown that this is one of the greatest droughts that we have ever experienced. This would seem to indicate that such a condition as actually obtains in northern Europe influences not only its own immediate vicinity, but territory a great distance away. The well-known tendency of natural forces to maintain an average might be the factor producing this startling inequality in the rainfall.

The Academy then adjourned.

EDMUND OTIS HOVEY,
Recording Secretary.

SECTION OF GEOLOGY AND MINERALOGY

5 OCTOBER, 1914

The Section was called to order at 8:15 p. m., Vice-President C. P. Berkey presiding.

There being no business to transact, the following scientific programme was offered:

Douglas W. Johnson, TOPOGRAPHIC FEATURES OF WESTERN EUROPE
AND THEIR INFLUENCE ON THE CAMPAIGN
AGAINST FRANCE.

SUMMARY OF PAPER

Professor **Johnson** described the salient features of geological structure west of the Rhine and explained the influence of this structure upon

surface topography. Special attention was given to the Rhine graben and the strong contrast between the steep eastern and gentle western slope of the Vosges; the maturely dissected peneplane of western Germany and the Ardennes trenched by the incised meandering valleys of the Rhine, Moselle and Meuse; the concentric *cuestas* northeast and east of Paris, with their steep escarpments facing toward the Germans; and the comparatively level plains of central and northwestern Belgium.

The topography of western Europe limited the Germans to four principal routes of invasion: (1) from Strassburg in the Rhine Valley over the Vosges or via the Belfort Gateway into France, and then over the successive *cuesta* scarps to Paris; (2) from Coblenz via the Moselle Valley route and Luxemburg into France, and then across the remaining *cuesta* scarps to Paris; (3) from Cologne via the Meuse Valley route through the Ardennes in Belgium to France, thus encountering a still smaller number of the *cuesta* scarps; and (4) from Cologne and Aix-la-Chapelle across the plains of Belgium through Brussels and Mons to northern France, and thence via Cambria and St. Quentin to Paris. This route (385 km.) is 50 per cent. longer from German territory to Paris than is the one most feasible (Moselle Valley route, with distance 260 km. from German border to Paris, air line), but is topographically the most favorable, although the choice involved longer lines of communication, the violation of Belgian neutrality and the possibility of war with Great Britain. Germany preferred that route whose topography most favored the rapid advance of great armies and heavy artillery in the face of an enemy.

The influence of topographic details upon maneuvers at different points of the battle lines was discussed, the strategic value of water gaps and wind gaps, marshes due to river capture, and *cuesta* scarps being especially evident in the battles of the Marne and Aisne.

The paper was illustrated with maps, charts and lantern slides.

The Section then adjourned.

A. B. PACINI,
Secretary.

SECTION OF BIOLOGY

12 OCTOBER, 1914

Section met at 8:15 P. M., Professor Raymond C. Osburn presiding.

The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

- W. D. Matthew**, NEW DISCOVERIES IN THE LOWER EOCENE MAMMALS.
W. K. Gregory, AN AMERICAN EOCENE LEMUR (*Notharctus* Leidy).

SUMMARY OF PAPERS

Dr. **Matthew** said in abstract: The many hundreds of mammalian fossils secured by the American Museum expeditions to the Lower Eocene of Wyoming and New Mexico, under Mr. Walter Granger, included material which had led to the following conclusions: (1) the Armadillo group, already known from *Metacheiromys* of the Middle Eocene, was also represented by aberrant genera in the Lower Eocene; (2) *Hyopso-*
pus, classed by earlier authors as a Primate and later as an Insectivore, proved to be a very primitive member of the Condylarthra; (3) certain upper and lower teeth bore a marked resemblance to those of the existing *Galeopithecus*, and may indicate the presence of the Dermoptera in the North American Lower Eocene; (4) a fragmentary jaw bore lower molars that are remarkably similar to those of certain extinct Patagonian genera allied to the Homalotheres. The faunistic bearing of these discoveries was discussed.

Dr. **Gregory** reviewed the systematic history of the family Notharctidæ, and illustrated some of the fossil and recent material which had led him to the following conclusions:

1) That the American Notharctidæ and the European Adapidæ are so closely related that they may well be regarded as belonging in a single family, the Adapidæ; including two subfamilies, the Adapinæ and the Notharctinæ. These diverged from each other at an early date, perhaps before the Middle Eocene, and followed different lines of evolution in Europe and in America. The family Adapidæ may be defined as follows:

$$\text{Dental formula} \quad I \frac{2}{2} \quad C \frac{1}{1} \quad P \frac{3}{3} \quad M \frac{3}{3}$$

Incisors with cutting edges and spatulate crowns. Canines caniniform not incisiform. Lacrymal not extended on face. Lacrymal foramen marginal. High sagittal and lambdoidal crests. Brain-case not much expanded. General architecture of skull substantially as in Lemuridæ, including mode of formation of auditory bullæ, position of tympanic annulus, course of internal carotid artery and position of all other foramina.

2) That the Notharctine division of the Adapidæ is also rather closely related to the stem of the existing Lemuridæ.

3) That the remote ancestors of all the higher Primates, especially the New World monkeys, went through a stage of evolution which is nearly represented by the more primitive members of the Notharctinæ, such as *Pelycodus frugivorus*; but that there are no known types which

actually bridge over the great structural gap between the higher Primates as a whole and the Notharctinæ.

The Section then adjourned.

WILLIAM K. GREGORY,
Secretary.

SECTION OF ASTRONOMY, PHYSICS AND CHEMISTRY

19 OCTOBER, 1914

Section was called to order at 8:15 p. m., Vice-President Charles Baskerville presiding.

The evening was devoted to the following lecture:

C. E. Ferree, THE EFFICIENCY OF THE EYE UNDER DIFFERENT CONDITIONS OF LIGHTING.

SUMMARY OF PAPER

Professor **Ferree's** communication gave the results of extensive experimentation in the illumination of lecture halls, recitation rooms, laboratories, etc.

A discussion of the paper followed.

The Section then adjourned.

E. E. SMITH,
Secretary.

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY

26 OCTOBER, 1914

Section met at 8:15 p. m., Professor Franz Boas presiding. The minutes of the last meeting of the Section were read and approved.

The following programme was then offered:

A. A. Goldenweiser, ORIGINS OF CLANS AMONG THE IROQUOIS.

Alanson Skinner, SOCIAL AND CEREMONIAL ORGANIZATIONS AND SOCIETIES OF THE IOWA INDIANS.

Robert H. Lowie, THE CULTURAL RELATIONS OF THE NORTHERN PAIUTE.

SUMMARY OF PAPERS

Dr. **Goldenweiser** said: The problem of clan origins has for years attracted the attention of ethnologists. The common assumption made about the origin of clans is that they have sprung from an original social

group through subdivision, the primal group often developing into a phratry.

Researches among the Iroquois of western New York and eastern Canada revealed three types of clan origins.

Type I. Origin by subdivision. This is seen in the common phenomenon of two clans bearing the name of the same animal but distinguished by an adjective. Here it was possible to prove that such clans originally constituted one clan, for they still preserve the same set of individual names.

Type II. Origin by fusion. A number of instances have come to light in which a Delaware and a Tuscarora clan of the same name, or an Oneida and a Tuscarora clan of the same name, have fused into one clan.

Type III. Origin from a maternal family. In one instance at least it can be shown that a maternal family consisting of individuals of one direct line of maternal descent, has developed into a clan distinguished as White Bear, whereas the other individuals of what was originally the same clan, are known as Black Bears or Bears.

It will be noted that in origins of types I and II conditions of locality and population must have been determining factors. There are reasons to believe, however, that not one of the above three types of origin represents the origin of clans which was most common in the history of society. I refer to the origin of clans from local groups which develop social solidarity through the exercise of common functions and intermarry, producing the local distribution of individual clans so characteristic of communities having clan or gentile systems. We may designate this type of origin, which has not so far been demonstrated by sufficient concrete data, as type IV. Conditions on the Northwest Coast make it all but certain that such was the predominant origin of clans in that area.

However that may be, the above instances, excepting type III, make it clear that the growth and depletion of a population on the one hand, and occupation of the same locality on the other, must have been all important factors in the history of clan origins.

Mr. **Skinner** said: The Iowa are divided into seven exogamic gentes, each of which is made up of four subgentes. Chieftainship is hereditary in the royal family of each subgens. The tribal chief is the chief of the Buffalo gens during spring and summer, and of the Bear gens during winter. On the march or hunt a chief is elected each night, his office expiring the following evening. In addition to the gentile system the tribe has three classes or castes: royalty, nobility, and commoners, which tend to be endogamous.

The societies and dances of the Iowa are of four types: military, social,

ancient, and modern mystery dances. Many of these are typical Plains military societies with the no-flight rite and crooked spear regalia, etc. The Helucka dance is important. Of mystery and animal dances the Buffalo dance and Medicine dance take first rank. The latter is a form of the Algonkin Midewin. Of modern societies and cults the Ghost Religion and Peyote ritual are foremost. The Peyote cult is rapidly doing away with all ancient customs.

Dr. **Lowie** explained that the Northern Paiute (Paviotso), who claim linguistic relation with the Bannock, had been in recent contact with the Shoshone on the east, and Washo and Pitt River Indians on the west, the latter figuring in tradition as their foremost enemies. Culturally, the Northern Paiute display interesting relations with both the Californian Indians and the Lemhi Shoshone. Some of their tales are especially suggestive of important Lemhi myths. On the other hand, the economic life, with its very extensive dependence on seeds, the high development of basketry, the use of the balsa, and other traits indicate a cultural connection with California.

The Section then adjourned.

ROBERT H. LOWIE.

Secretary.

BUSINESS MEETING

2 NOVEMBER, 1914

The Academy met at 5:05 P. M. at the American Museum of Natural History, President George F. Kunz presiding.

The minutes of the last business meeting were read and approved.

The following candidates for membership in the Academy, recommended by Council, were duly elected:

ACTIVE MEMBERSHIP

Milo Hellman, 40 East 41st Street.

ASSOCIATE MEMBERSHIP

Samuel H. Knight, Dept. Geology, Columbia Univ.

The Recording Secretary reported the following death:

F. F. Hahn, Associate Member since 1912, in one of the German attacks on Nancy, France.

The Academy then adjourned.

EDMUND OTIS HOVEY,

Recording Secretary.

SECTION OF GEOLOGY AND MINERALOGY

2 NOVEMBER, 1914

Section met at 8:15 P. M., Vice-President C. P. Berkey presiding.

No business was transacted, and the evening was devoted to the following lecture:

Reginald A. Daly, PROBLEMS OF VOLCANIC ACTION.

SUMMARY OF PAPER

Professor **Daly** said in abstract: To understand the constitution of the earth it is necessary to know the mechanism of its volcanoes. Progress in completing that knowledge depends on the making of rigorous distinction between the essential and the subsidiary questions regarding volcanic activity. Among the essential questions are: What is the first step in volcanism? How is a volcanic vent opened? How is its activity continued? Why is that activity intermittent? Why are some vents arranged in lines while others are grouped in clusters? What are the causes of volcanic explosions, of lava outflow, and of variations in the character of lavas? The measure of contemporary success in solving these problems was considered.

After the lecture a collation was served in the Eskimo Hall. A reception to Professor Daly followed, and the Section then adjourned.

A. B. PACINI,
Secretary.

SECTION OF BIOLOGY

9 NOVEMBER, 1914

Section met at 8:15 P. M., Professor Raymond C. Osburn presiding. The minutes of the last meeting of the Section were read and approved.

The following nomination for the year 1915 was made and approved for transmission to the Council:

For Vice-President of the Academy and Chairman of the Section: Professor Raymond C. Osburn.

Dr. W. K. Gregory was elected Secretary for the year 1915.

The following programme was then offered:

George T. Stevens, SOME ELEMENTARY FORMS AND PHENOMENA IN
THE EVOLUTION OF VISUAL PERCEPTION.

W. K. Gregory, OBSERVATIONS ON THE INDRIKINE AND OTHER
LEMURS.

SUMMARY OF PAPERS

Dr. **Stevens** summarized the results of his microscopic studies under the following topics, which were illustrated by enlarged drawings:

- (1) Under the influence of light the most simple forms of plant life behave much as do the most elementary forms of animal life.
- (2) Plants of a single cell move about as though controlled by will power, seek or avoid the stimulus of luminous waves.
- (3) There is a gradual evolution of what we call visual sense, from the most elemental impression to the complete perception of form, size and color of objects.
- (4) Primitive visual organs in leaves of certain plants.
- (5) Illustrations of the influence of luminous waves shown by various plants and animals rising gradually in the scale of organism.
- (6) Specialization of locations and organs for sensibility to luminous impressions.
- (7) Visual organs in more advanced forms.
- (8) Nature of sense of perception of form.

Dr. **Gregory** illustrated the osteology of the principal recent and extinct members of the Indrisinæ, a group of herbivorous Malagasy Primates, showing that in the more deep-seated characters of the skull and limbs the Indrisinæ are true Lemurs, and that structurally they represent a specialized herbivorous modification of the primitive Eocene lemur type.

The Section then adjourned.

WILLIAM K. GREGORY,
Secretary.

SECTION OF ASTRONOMY, PHYSICS AND CHEMISTRY

16 NOVEMBER, 1914

Section was called to order at 8:15 P. M., Vice-President Charles Baskerville in the chair.

The minutes of the last meeting of the Section were read and approved.

The nomination of officers for 1915 was referred to the Council.

The scientific programme of the evening consisted of the following titles:

James Kendall, IONIZATION EQUILIBRIUM.

Reinhard A. Wetzel, THE STARK EFFECT OR ELECTRIC RESOLUTION OF THE SPECTRA OF THE ELEMENTS.

SUMMARY OF PAPER

Mr. **Kendall** said in abstract: The *divergences* from the dilution law exhibited by acids in aqueous solution have been critically investigated.

The increase in the dissociation constant when the ionic concentration is large is found to be represented quantitatively by the equation: $y^2/(1-y) \cdot v = k + c(1-y)/y$. This empirical formula is applicable to acids of all strengths.

The decrease in the dissociation constant when the total concentration is large is found to disappear under the assumption that ionization is not spontaneous, but induced by the solvent. The legitimacy of this assumption has been discussed, and the experimental data shown to be in its support. The dissociating power of the solvent is ascribed to its unsaturated character, *i. e.*, to the presence of free valences.

A discussion followed.

The Section then adjourned.

E. E. SMITH,
Secretary.

SECTION OF ANTHROPOLOGY AND PSYCHOLOGY

23 NOVEMBER, 1914

Section met in conjunction with the New York Branch of the American Psychological Association at Columbia University, Professor R. S. Woodworth presiding.

The following nomination for Vice-President of the Academy and Chairman of the Section was approved for transmission to the Council:

Dr. Clark Wissler, American Museum of Natural History.

Dr. Robert H. Lowie was elected Secretary of the Section for the year 1915.

The following scientific programme was then offered:

Wayne P. Smith,	SOME ASPECTS OF EMOTIONAL REACTIONS.
Garry C. Myers,	MOTOR-EMOTIONAL EXPRESSION OF AN INFANT.
H. L. Hollingworth,	THE LOGIC OF INTERMEDIATE STEPS.
Richard H. Paynter,	EXPERIMENT <i>vs.</i> COURT DECISION.
C. Homer Bean,	DEMONSTRATION OF PSYCHOLOGICAL APPARATUS.

SUMMARY OF PAPERS

Mr. Smith:

Importance of Emotion.—Psychological study is beginning to confirm common observation as to the significance of the feelings and emotions in behavior. Educational practice has been in advance of educational theory; for it has sought to utilize feelings and emotions in development of sane and efficient social workers. It has recognized that things that affect or evoke emotional reaction and tend to get more immediate motor

response, command more thorough consideration and interpretation than do those without this "appeal" or emotional character. From feeling as the elemental evaluation of things for life springs inquisitiveness, or the whole knowledge process. The chief function of knowledge seems to be to clarify, that is, to emphasize and unify in a larger perspective, the values of things to which response is to be made.

Conditions of Emotional Reaction.—Emotivity depends first upon the nature of the individual as determined by race, sex, age, environment, and disposition; second, on the state of the individual as determined by fatigue, health, inertia, and the functioning of certain organs, especially the cerebral cortex, the skin, certain sense organs and the alimentary canal, sexual organs, certain "ductless" glands, the circulatory and in a possibly less degree the respiratory system; third, by certain psychic conditions as attitude, interest, preoccupation, suggestibility, psychical habits of relatively dependable character in presence of certain emotive stimuli, and finally the interpretation of the situation. All the conditions that contribute to euphoria and dysphoria are involved likewise in the emotional reactions of an individual.

In a more specific way emotional reaction depends upon the kind and degree of organization of an individual. This varies from one pole to the opposite. One extreme type is almost chaotic, incoherent, impulsive and explosive, indiscriminately responsive to all sorts of stimuli. The other extreme is highly centralized, exclusively narrow, mono-ideistic or *idée fixe* in character. In the latter class all vital tendencies and interests are dominated through repression, or perversion, by a single zone which has a hair-trigger responsiveness to suitable emotional stimulation. Outside this zone such an individual shows apathy, a kind of poise, and a comprehensive "*nil admirari*" attitude. Variations of this type may be found not only in industrial fields where occupation and circumstance may be responsible, but also in such fields as religion, art, morality, even science and philosophy. Organization tends to establish almost insuperable psychic barriers against all stimuli external to the particular zone of interest.

Emotivity are also determined by degree of "intellectual control," and this is not to be confused with "organization" just cited. In those in whom intellectual control is most highly developed, all emotive excitations are taken as problems of knowledge. Even "shocks" are effectually dealt with by a system of psychic defenses and controls. A standard of "emotionless" behavior may obtain. There are of course many variations from the extreme. A general statement may be made that "emotivity varies inversely as intellectual control."

Function of Emotional Reaction.—Psychological research shows that emotional reactions have a valuable positive as well as an apparently negative function. They are more important than to serve merely as symptoms or psychic effects of sensory and motor excitation. They have a causative function as recent investigation shows. The function may be summarized as follows:

1). Emotions of the more intense kind signalize the compresence of several motor tendencies which evoked by the perception of the situation are incoördinate, mutually conflicting and inhibitory in their struggle for expression. They are moreover inhibitory of immediate overt action, in very large measure at all events, by the organism. Such immediate emotive responses as usually occur may be means of protection or communication or mere vestiges of acts that have survived the period of their utility. Among these acts may be mentioned convulsive movements, "freezing," cries or growls, trembling, facial contortions and flushing or pallor of face, hair standing on end, parched mouth and throat, and so on; many more or less prophylactic or communicative, but some certainly belonging to levels of behavior not adapted to the present.

2). Emotional reactions make possible and necessary novel and more satisfactory mode of behavior. Momentary inhibition of gross organic response by emotion allows a rapid survey of the situation and incited motor tendencies, both old and new, and a selective organization of these tendencies into a fit plan of action. This clarification of the situation as a whole is accompanied by a gradual subsidence of intense emotion into a vigorous emotional tinge that reinforces and "moves" the whole organism to action. The outcome of the plan reflexly qualifies the remembered experience as "emotional meaning" which is utilized in future experience.

3). Emotion not only reinforces and gives ultimate directness and quickness to the plan of behavior adopted; but it also sets free energy and makes it available for immediate consumption. Old accounts say that emotion animates and invigorates with the heat and flush of swiftly-flowing blood, "anger sweetens the blood," reveals a sense of new and greater powers and a faith and zeal that carry one to successful issue. Experimental researches support this popular idea. See among others the accounts of physiological experimentation of Benedict and Cathcart, F. S. Locke, Vincent, Sherrington, Schäfer, Bickel, Bickel and Sasaki, Cannon, Pawlow. It is fairly to be inferred from data available that "big" emotions as fear, anger and possibly love, stimulate through sympathetic connections certain organs as the thyroid and the adrenal glands. The stimulation of the adrenals effects secretion of adrenalin into the

blood, which at once accelerates heart action and circulation of blood, changes the chemical nature of the blood and size of blood vessels, sets free in more than usual amount "blood sugar" from the liver, which with the increased supply of oxygen through quickened respiration provides with necessary energy whatever parts of the organism are concerned in the work to be done. These emotions also by influence upon other glands and organs suppress temporarily alimentary and other processes not serviceable in the given crisis of behavior. The sense organs may be made hypersensitive or partly suppressed. Mobilization and utilization of energy is the essential business of certain emotions. Other processes are held in abeyance. The organism is delicately and accurately adaptable to situations that affect it. The emotions are instrumental in facilitating adaptation, in setting free extra energy, and in "moving" the whole organism to the efficient achievement of the work that must be done.

4). With the development of an individual emotional reactions tend to lose their "bigness" and intensity in some measure and in combination with other factors to be sublimated into attitudes and sentiments of dependable character and utility in behavior. Emotional as well as other aspects of experience are susceptible of organization into psychic controls. Such controls are modesty, sympathy, love, loyalty, patriotism, and other familiar sentiments. With this feature of emotion education is especially concerned.

Mr. **Myers's** report was based on a rather extensive observation of a baby's emotional expression by the arms and legs, during his first year. If the behavior of the child studied is typical, it seems that pleasurable movements are at first random, due perhaps to lack of coördination of the moving members. Soon these movements became alternate. In this case, the one member of the pair being stimulated to response, consequently suffers fatigue, and the other member, due gradually to coördinating motor pathways, takes up the movements, which in turn shifts to the first again, etc., until both are accumulatively fatigued, or the stimulus is too weak to elicit a response, or both. Then, with development, each member of the moving pair becomes less susceptible to fatigue, and, in accordance with the law of habit, tends to repeat its own movement, resulting in rhythmical, successive movements by the same limb. Later the coördination, in greater perfection, provides unified expressions by the pairs of the limbs. Finally, single movements of either member of the pair may be set up in response to a strong feeling, or the unified movements may be more speedy and graceful. Therefore, the character

and speed of motor emotional reactions by the limbs, are determined by the degree of coördination of the members of the moving pairs.

Motor-emotional expressions are apparently the most primitive as well as the most fundamental. These movements seem to serve as drill exercises to discipline the limbs into definite forms of motor reactions, out of which grow the useful and voluntary acts of the individual.

Aside from the movements of the first few weeks, emotional expressions by the limbs tended to occur in successive series, with the number of movements per series varying from 1 to 18 and with a central tendency of from 3 to 5 per series. Between the series the interval of time was but a little less than the total time for the series. The rate of movement increased with the increase of motor coördination.

These (rhythmical) movements began on the left side, then were transferred to the right. For example, the left hand began a regular drumming movement on the 123rd day; the right hand began the same type of movement on the 141st day. The left leg, 139th day; right leg, 143rd day. Unified movements by the legs began on the 148th day, and were well developed by the 189th day. Unified movements by the arms began the 177th day and were well developed by the 247th day.

However, the transition from one type of movement to another was gradual; and, while new movements for emotional expression became more numerous as time went on, the old movements were occasionally revived and seem never to have wholly died out.

Pleasure tends to induce and accelerate activity and displeasure to inhibit and retard activity.

Pleasurable motor expressions tended to reach their maximum and to cease, at an appreciable interval before the real pleasurable experience which was in anticipation, *i. e.*, anticipation at its climax seemed to give greater pleasure than the real experience of the thing anticipated.

Unified hand movements, which, by the last few months of the year tended to be toward each other, ceased at the end of the series, with the hands coming together, palm to palm. As the speed and force of these movements of pleasure increased, they finally came together with a clap, and gradually, instead of the introductory unified movements there developed the regular clapping of the hands as expression of a high degree of pleasure. Therefore, one of the most primitive expressions of pleasure is applause.

Dr. **Hollingworth** called attention to various cases in the literature of psychology, sociology and anthropology (Clarke, Titchener, Brentano, Stout), in which the existence of morphological intermediaries between two types or processes is taken to indicate their identity of quality or

their genetic relationship. Other cases were cited in which the validity of this argument has been questioned (Miller, Bergson, McDougall, Bateson). The type of argument in question was shown to have resulted in various biological and philosophical enormities, and specific cases were presented illustrating the ease with which the error may be committed. The argument was shown to be but a particular case of the logical fallacy of "affirming the consequent" and to be meaningless unless supported by accessory evidence. It was urged that the inadequacy of the logic of intermediaries should be more fully realized in psychological investigation.

Mr. Paynter: An experiment was conducted to determine the amount of confusion between trade-names and their imitations, and to compare the results with the legal decisions. The decisions of the legally allowable amount of similarity, confusion, or deception between trade-names and their imitations were rendered by judges of State and Federal Courts, and by various Commissioners of Patents. Legally, a "probability of deception" between the original and imitating trade-names constitutes an infringement. But the phrase "probability of deception" has a variable meaning and has not been objectively measured. Experiment, on the other hand, can state the amount of confusion arising between two trade-names by the per cent. of individuals actually deceived by the imitation. Furthermore, experiment can state the reliability of court decisions by calculating to what extent the scores of the infringing imitations are psychologically more confusing than the non-infringing.

Recognition was the method used. Thirty-nine cases were studied, 24 of which were infringements and 15 non-infringements. The averages, medians, modes and great per cent. of overlapping showed that the difference between the infringements and the non-infringements (as judged by the courts and Commissioners) was so small in comparison with the differences within them as to make the decisions very unreliable. In only 6 cases out of 9 which the experiment most easy to judge were the decisions really correct. The results of two groups of subjects, an uninformed group and an informed, both confirmed the above conclusion. The application of the recognition method will constitute an enormous saving in time, energy and money over the present legal procedure of the courts and Patent Office. The Trade-Mark Act of 1905 and the interpretation by the Supreme Court of the United States define an infringement as a "colorable imitation" or such as is "calculated to mislead." These indefinite and variable meanings of infringement should be replaced by a quantitative statement of the per cent. of individuals which must be deceived.

Dr. Bean demonstrated two pieces of apparatus. The one is a balance,

that may be varied in single milligrams, to find thresholds of touch. The balance beam is a glass tube with the scale in millimeters and centimeters etched upon it. This beam is bent downward at one extremity where a fibre contact surface is attached. The weight is varied by shifting a straight wire inside the tube. Two meters of this wire would weigh one grain. Therefore, when a convenient length of it is moved toward the contact end of the beam one millimeter, it adds one milligram to the pressure upon the skin, because the millimeter added to the one end is subtracted from the opposite end. This is a welcome substitute for Willyoung's troublesome pith ball apparatus. It is more rapidly and easily operated and thus avoids fatigue in both persons. The weight can be lowered upon the skin at the same rate in successive trials. There are no tiny weights to roll and produce tickle sensations that are easily confused with contact sensations. The results are for this reason less variable, and the thresholds are found to be somewhat lower than can be determined with Willyoung's pith weights.

The other apparatus is an animal maze contrived for the purpose of lengthening the process of learning that it may be studied to better advantage. The curve of learning derived from experiments with the old form of maze that consists of a few long alleys, drops with an immediacy that shows that the animal learned the trick in his first trial, and that later progress is of an altogether different sort. The maze demonstrated contains no alleys, but consists of triangular rooms with equal sides. The rooms are themselves equal in size and juxtaposed like the cells of a honey comb. When the animal enters a room through a door in the middle of one side, it sees a door in each of the other walls. One of these doors opens into a room with no other door, whereas the other leads to food and friends. The curve found is like that for most of the experiments in which the material must be learned gradually.

The Section then adjourned.

ROBERT H. LOWIE,
Secretary.

BUSINESS MEETING

7 DECEMBER, 1914

The Academy met at 8:15 P. M. at the American Museum of Natural History, President George F. Kunz presiding.

The minutes of the last business meeting were read and approved.

The following candidates for membership in the Academy, recommended by Council, were duly elected:

ACTIVE MEMBERSHIP

- Allison V. Armour, 10 West 43rd Street, City.
Ledyard Avery, 18 St. Nicholas Place, City.
Charles Baird, 130 East 67th Street, City.
Hugh Potter Baker, N. Y. State College of Forestry, Syracuse, N. Y.
Otto F. Behrend, 210 West 8th Street, Erie, Pa.
William H. Bliss, 6 East 65th Street, City.
William F. Beller, 51 East 123rd Street, City.
Henry Bird, Rye, New York.
Francis P. Dodge, Plaza Hotel, City.
G. Clyde Fisher, American Museum of Natural History, City.
George H. Hazen, 381 Fourth Avenue, City.
Samuel Heller, 68 Nassau Street, City.
Alfred Harris, Babylon, New York.
Paul Griswold Howes, Maplewood Biological Laboratory, Stamford, Conn.
Alice J. Johnson, Trinity College, Washington, D. C.
John Devereux Kernan, M. D., College of Physicians and Surgeons, City.
Edward Lindsey, Warren, Pa.
Mrs. Morris Loeb, 273 Madison Avenue, City.
Marion McMillin, 40 Wall Street, City.
Adam M. Miller, Long Island College Hospital, Brooklyn, N. Y.
Clyde Milne, 229 West 78th Street, City.
Russell Hastings Millward, Hotel Ansonia, City.
Wesley C. Mitchell, 37 West 10th Street, City.
Robert Cushman Murphy, Brooklyn Museum, Brooklyn, N. Y.
Ignaz Matausch, American Museum of Natural History, City.
Arthur Notman, Globe, Arizona.
T. H. Hoge Patterson, 4231 Walnut Street, Philadelphia, Pa.
R. C. Rathborne, 14 Congress Street, Newark, N. J.
C. P. Schlicke, 440 Washington Street, City.
Marie F. C. Stockmann, 61 West 127th Street, City.
Carl Stoeckel, Norfolk, Conn.
I. Frank Stone, 100 William Street, City.
Frederick Tilney, College of Physicians and Surgeons, City.
C. H. T. Townsend, U. S. National Museum, Washington, D. C.
F. W. Vanderbilt, Grand Central Terminal, City.
J. P. Wintringham, 153 Henry Street, Brooklyn, N. Y.
Mrs. H. W. Warner, 62 E. 67th Street, City.

ASSOCIATE MEMBERSHIP

Harold H. Plough, Columbia University, City.

The Recording Secretary reported the following deaths:

August Weissman, Honorary Member since 1909, died 6 November, 1914.

Charles Sedgwick Minot, Corresponding Member since 1878, died 19 November, 1914.

Theo. N. Gill, Corresponding Member since 1858, died 25 September, 1914.

J. Selden Spencer, Corresponding Member since 1890, died 3 December, 1914.

The Academy then adjourned.

EDMUND OTIS HOVEY,
Recording Secretary.

SECTION OF GEOLOGY AND MINERALOGY

7 DECEMBER, 1914

Section was called to order by Vice-President C. P. Berkey, about 25 members and guests being present.

An application for a grant of one hundred dollars from the John Strong Newberry Fund, by Dr. Charles R. Eastman, a member and Fellow of the Academy, to continue his studies on the Paleozoic fishes of North America, was communicated to the Section. It was accompanied by a communication by Dr. Bashford Dean, and one by Dr. William K. Gregory, bearing testimony to the value of Dr. Eastman's researches.

On motion of Dr. Hovey, the Section approved the grant.

The Section also voted to approve the application of Dr. Berkey for an assistant in examining the material secured in Porto Rico.

Dr. Hovey announced the nomination by the Council of Dr. Berkey as Vice-President of the Academy and Chairman of the Section for the ensuing year. The action of the Council was approved.

Dr. A. B. Pacini was elected Secretary of the Section for the year 1915.

The following scientific programme was then offered:

Henryk Arctowski, VOLCANIC DUST VEILS AND CLIMATIC VARIATIONS.
C. C. Mook, A STATISTICAL STUDY OF VARIATION IN *Spirifer mucronatus*.

SUMMARY OF PAPERS

Dr. **Arctowski** gave the result of his investigations on the influence that the violent eruptions of the years 1883, 1902 and 1912 have had upon atmospheric temperature.

It was found that the pleionian variations of temperature changes have nothing in common with the presence or absence of volcanic dust veils; that the dust veils produced by the Krakatoa eruption affected atmospheric temperature very greatly and that the violent volcanic eruptions of 1902 as well as the Katmai eruption of 1912 influenced the yearly mean temperatures but very slightly or not at all.

This paper was discussed by Professor Kemp and others.

Mr. **Mook** said: A study was made upon five mutations of *Spirifer mucronatus* from the Hamilton beds of Michigan and Ontario. Many specimens were measured, and shell indices were computed by dividing the width of the shell by its length. Curves were plotted of the percentage of the total number of individuals measured of each mutation, with indices between certain arbitrary limits, both for adult and neanic stages. Comparison was made between the curves of the adult and neanic stages of each mutation, and of the curves of the adults of the various mutations with each other.

The tendency in evolution has been to reduce the shell index, reduce the number of plications, lose the groove on the fold and the plication in the sinus, strengthen the growth lines, deepen the sinus, and to a certain extent to reduce the actual width of the shell.

The paper was discussed by Mr. F. K. Morris and Prof. A. W. Grabau. The Section then adjourned.

A. B. PACINI,
Secretary.

SECTION OF BIOLOGY

14 DECEMBER, 1914

Section met at 8:15 P. M., Professor Raymond C. Osburn presiding. The minutes of the last meeting of the Section were read and approved. The following programme was then offered:

SYMPOSIUM ON PORTO RICO

Charles P. Berkey,

GEOLOGICAL RECONNAISSANCE OF PORTO
RICO.

N. L. Britton,

PROGRESS OF THE BOTANICAL INVESTIGATION.

Marshall A. Howe,	PRESENT KNOWLEDGE OF THE MARINE ALGÆ.
N. Wille,	PRESENT KNOWLEDGE OF THE FRESH-WATER ALGÆ.
Roy W. Miner,	PRESENT KNOWLEDGE OF THE MARINE IN- VERTEBRATES.
Frank E. Lutz,	PRESENT KNOWLEDGE OF THE INSECTS AND SPIDERS.
John Treadwell Nichols,	PRESENT KNOWLEDGE OF THE FISHES AND OTHER VERTEBRATES.

SUMMARY OF PAPERS

The progress of the Academy's Natural History Survey of Porto Rico was summarized in the papers as follows:

Professor **Berkey** outlined his geological reconnaissance of the island, in which he and Dr. Fenner had traveled over 2,000 miles; they had studied the rocks at so many points that they were enabled to construct a preliminary geological map which was much more accurate than any hitherto made; from their studies the broader geological history of the island was revealed.

Professor **Britton** outlined the progress of the botanical investigation. The material collected by the Academy workers had been distributed to a number of specialists in different parts of the country and from their labors the knowledge of the flora was rapidly extending.

Dr. **Howe** by means of the stereopticon exhibited a series of marine algæ recently collected by himself. Especially interesting were the reef-building corraline algæ.

Dr. **Wille** summarized the present knowledge of the fresh-water algæ, Mr. **Miner** described the results of his collecting of marine invertebrates; Dr. **Lutz** outlined the present knowledge of the insects and spiders, touched upon several interesting problems in distribution and alluded to the importance of studying the West Indies as a whole; Mr. **Nichols** described the fish fauna.

The Section then adjourned.

WILLIAM K. GREGORY.

Secretary.

ANNUAL MEETING

21 DECEMBER, 1914

The Academy met in Annual Meeting on Monday, 21 December, 1914, at the Hotel Martinique, at the close of the annual dinner, President George F. Kunz presiding.

The minutes of the last Annual Meeting, 15 December, 1913, were read and approved.

Reports were presented by the Corresponding Secretary, the Recording Secretary, the Librarian and the Editor, all of which, on motion, were ordered received and placed on file. They are published herewith.

The Treasurer's report showed a net cash balance of \$1,274.97 on hand at the close of business, 30 November, 1914. On motion, this report was received and referred to the Finance Committee for auditing.

The following candidates for Fellowship, recommended by the Council, were duly elected:

Professor George I. Finlay, New York University,
Professor George S. Huntington, College of Physicians and Surgeons,
Professor James Howard McGregor, Columbia University,
Mr. Alois von Isakovics, Synfleur Scientific Laboratories, Monticello,
Professor H. von W. Schulte, College of Physicians and Surgeons,
Dr. Elvira Wood, Museum of Comparative Zoölogy.

The Academy then proceeded to the election of officers for the year 1915. The ballots prepared by the Council in accordance with the By-Laws were distributed. On motion, it was unanimously voted that the Recording Secretary cast one affirmative ballot for the entire list nominated by the Council. This was done and they were declared elected, more than the requisite number of members and Fellows entitled to vote being present.

President, GEORGE F. KUNZ.

Vice-Presidents, CHARLES P. BERKEY (Section of Geology and Mineralogy), RAYMOND C. OSBURN (Section of Biology), CHARLES BASKERVILLE (Section of Astronomy, Physics and Chemistry), CLARK WISSLER (Section of Anthropology and Psychology).

Corresponding Secretary, HENRY E. CRAMPTON.

Recording Secretary, EDMUND OTIS HOVEY.

Treasurer, EMERSON McMILLIN.

Librarian, RALPH W. TOWER.

Editor, EDMUND OTIS HOVEY.

Councilors (to serve 3 years), BASHFORD DEAN and C. STUART GAGER.

Finance Committee, FREDERIC S. LEE, JOHN TATLOCK and W. J. MATHESON.

At the close of the elections, Dr. **George F. Kunz** gave his address as retiring President, entitled

"THE NEW YORK ACADEMY OF SCIENCES, ITS PAST, ITS PRESENT AND ITS FUTURE,"

after which the Academy and guests listened to an address by Mr. **Raymond L. Ditmars**, Curator of Reptiles at the New York Zoölogical Park, on the

"BOOK OF NATURE,"

illustrated with some of his latest motion-picture reels showing various phases of most interesting animal life.

The Academy then adjourned.

EDMUND OTIS HOVEY,
Recording Secretary.

REPORT OF THE CORRESPONDING SECRETARY

We have lost by death during the past year the following Honorary Members:

Sir John Murray, elected 1912, died 16 March, 1914,
Heinrich Rosenbusch, elected 1887, died 20 January, 1914,
August Weissmann, elected 1909, died 6 November, 1914,

and the following Corresponding Members:

Theodore Nicholas Gill, elected 1858, died 25 September, 1914,
Seth E. Meek, elected 1888, died 7 July, 1914,
Charles Sedgwick Minot, elected 1878, died 19 November, 1914,
J. Selden Spencer, elected 1890, died 3 December, 1914,
N. H. Winchell, elected 1898, died 1 May, 1914.

Two Corresponding Members have been elected Honorary Members.

There are at present upon our rolls 47 Honorary Members and 115 Corresponding Members.

Respectfully submitted,

HENRY E. CRAMPTON,
Corresponding Secretary.

REPORT OF THE RECORDING SECRETARY

During the year 1914, the Academy held 9 business meetings and 27 sectional meetings, at which 72 stated papers were presented as follows:

Section of Geology and Mineralogy, 18 papers; Section of Biology, 22 papers; Section of Astronomy, Physics and Chemistry, 7 papers; Section of Anthropology and Psychology, 25 papers.

Four of the sectional meetings were of general character and of par-

ticular interest and were followed by a social hour, with refreshments, in one of the exhibition halls of the Museum.

The first was held under the auspices of the Section of Biology on the evening of 12 January, when a "Conference on the Piltdown Skull and the Origin of Man" was participated in by Professor Henry Fairfield Osborn, Dr. J. Leon Williams, Professor R. Broom and Dr. W. K. Gregory. The second was held on 16 February, under the auspices of the Section of Astronomy, Physics and Chemistry, when Professor H. T. Barnes, of McGill University, lectured upon "The Physical Effects Produced by Icebergs in the North Atlantic." The third meeting was held on the evening of 23 March, under the auspices of the Section of Anthropology and Psychology; Professor Hiram Bingham, of Yale University, delivered a lecture on "Recent Exploration in the Land of the Incas." The fourth, held on 2 November, was under the auspices of the Section of Geology and Mineralogy, and Professor Reginald R. Daly lectured upon "Problems of Volcanic Action."

In addition to these general meetings of the Academy, one public lecture was given to the members of the Academy and the Affiliated Societies and their friends on 30 April by Dr. L. A. Bauer, Director of the Department of Terrestrial Magnetism at Washington. The title was "Following the Compass."

At the present time the membership of the Academy is 497, which includes 478¹ Active Members (of whom 19 are Associate Members, 124 Fellows, 98 Life Members and 10 Patrons) and 19 Non-resident Members. There have been 11 deaths during the year, 22 resignations have become effective and three names have been dropped from the roll. One member has been discontinued temporarily at her own request. Fifty-four new members have been elected during the year, one of whom failed to qualify and five of whom commuted their annual dues by a single payment of \$100 each. One patron has been elected. Two names have been transferred to the life membership list on account of twenty-five years' payment of annual dues. Four associate members have taken up active membership. As the membership of the Academy a year ago was 481, there has been a net gain of 16 during the year 1914. Record is made with regret of the loss by death of the following active and associate members:

Albert S. Bickmore, Active Member since 1873.

Samuel H. Bishop, Active Member since 1907.

Henry W. Boettger, Active Member since 1905.

¹ Including 38 members-elect who have not yet paid their first annual dues.

F. F. Hahn, Associate Member since 1912.
 Karl Hutter, Active Member since 1910.
 Dwight A. Jones, Active Member since 1905.
 J. Langeloth, Active Member since 1905.
 Mrs. Charles Tyler Olmsted, Active Member since 1907.
 Charles J. Perry, Active Member since 1905.
 David L. Pettigrew, Active Member since 1896.
 George Taylor, Active Member since 1907.

Respectfully submitted,

EDMUND OTIS HOVEY,
Recording Secretary.

REPORT OF THE LIBRARIAN

During the current year the Library of the New York Academy of Sciences has received by exchange and donation two hundred eight volumes and one thousand five hundred twenty-two numbers. The Naturhistorisches Verein in Augsburg has very graciously supplied the Academy Library with volumes III (1850), V-XIII (1852-1860), which were lacking in the files and for which special acknowledgments are herewith extended.

Through the system of inter-library loans the scientific books have been made more accessible to students and investigators, and it is therefore a pleasure to report that the use of the library has much increased.

Respectfully submitted,

RALPH W. TOWER,
Librarian.

REPORT OF THE EDITOR

The parts of the Annals which have been published this year are the following:

VOLUME XXIII

	Pages
A. C. Hawkins—Lockatong Formation of the Triassic of New Jersey and Pennsylvania.....	145-176
Marjorie O'Connell—Revision of the Genus Zaphrentis.....	177-192
Charles R. Fettke—The Manhattan Schist of Southeastern New York State and Its Associated Igneous Rocks.....	193-260
E. O. Hovey—Records of Meetings of the Academy.....	261-316
Charter and Organization of the Academy.....	317-322
Constitution and By-laws.....	323-330
Membership of the Academy.....	331-342
Index.....	343-358

VOLUME XXIV

Elvira Wood—The Use of Crinoid Arms in Studies of Phylogeny.... 1-17
C. C. Mook—Notes on Camarasaurus Cope..... 19-22
Alexis A. Julien—The Genesis of Antigorite and Talc..... 23-38
Henryk Arctowski—A Study of the Changes in the Distribution of
Temperature in Europe and North America dur-
ing the Years 1900-1909..... 39-113
Raymond Bartlett Earle—The Genesis of Certain Paleozoic Interbed-
ded Iron Ore Deposits..... 115-170

There is likewise in press a paper by W. D. Matthew entitled "Climate and Evolution" and one by H. von W. Schulte and Frederick Tilney entitled "Development of the Neuraxis in the Domestic Cat to the Stage of Twenty-one Somites." The first portion of Miss Laura E. W. Benedict's paper on "Bagobo Ceremonial, Magic and Myth" is in press. This is to form the first paper of Volume XXV of the Annals which is to be devoted exclusively to anthropological papers. The Publication Committee has accepted a paper by W. K. Gregory entitled "Present Status of the Problem of the Origin of the Tetrapoda," for publication in Volume XXVI of the Annals.

Respectfully submitted, EDMUND OTIS HOVEY,
Editor.

REPORT OF THE TREASURER

MEMBERSHIP

Paid up, Active Members (2 of these were elected after 1 May and paid \$5 for 1914).....	272
Paid up, Associate Members.....	17
Delinquent Active and Associate Members.....	51
Life members and Patrons.....	104
	<hr/>
	444 ¹

RECEIPTS

DECEMBER 1, 1913—NOVEMBER 30, 1914

Cash on hand, December 1, 1913.....	\$2,821.67
Life membership fee.....	100.00
Income from investments:	
Interest on mortgages on New York City real estate..	\$771.26
Interest on railroad and other bonds.....	1,325.00
	<hr/>
	2,096.26

¹ Including four deceased members whose dues have been paid to the end of the year.

RECORDS OF MEETINGS

405

Interest on bank balances.....		40.55
Active membership dues, 1912.....	30.00	
“ “ “ 1913.....	115.00	
“ “ “ 1914.....	2,710.00	
	<hr/>	2,855.00
Associate membership dues, 1912.....	3.00	
“ “ “ 1913.....	3.00	
“ “ “ 1914.....	51.00	
	<hr/>	57.00
Sales of publications.....		195.85
Contribution to cost of publication.....		250.00
Subscriptions to annual dinner (1913).....		188.00
Esther Herrman Research Fund (return of grant).....		150.00
Part payment on Deane-Brennan mortgage.....		1,163.33
Sale of Lawyers' Mortgage Company's bond.....		1,000.00
Porto Rico Survey (subscription).....		1,000.00
Porto Rico Government (refund of advances made on account of field expenses).....		1,990.82
Cash on note in bank.....		3,000.00
Loan from American Museum of Natural History.....		250.00
	<hr/>	
Total.....		\$17,158.48

DISBURSEMENTS

DECEMBER 1, 1913—30 NOVEMBER, 1914

Publications on account of Annals.....	\$2,165.96
Publication of <i>Bulletin</i>	607.86
Recording Secretary's expenses.....	417.82
Recording Secretary's and Editor's allowances.....	1,500.00
Lecture Committee.....	98.40
General expenses.....	149.60
Esther Herrman Research Fund (grants).....	990.00
John Strong Newberry Fund (grants).....	75.00
Annual meeting and dinner (1913).....	226.30
Annual dues, 1913 (refund).....	10.00
General meetings.....	861.20
Headquarters Committee.....	324.49
Purchase of mortgage from Lawyers' Mortgage Company.....	2,000.00
Porto Rico Survey (advances for field expenses).....	3,000.00
Section of Geology and Mineralogy.....	20.43
Section of Biology.....	39.28
Special Membership Committee.....	100.00
American Museum of Natural History (repayment of loan).....	250.00
Payment of note in bank.....	3,000.00
Interest on note in bank.....	47.17
Cash on hand.....	1,274.97
	<hr/>
Total.....	\$17,158.48

Investments (cost)	\$42,362.92
Cash on hand.....	1,274.97
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	\$43,637.89

Permanent Fund	\$23,012.57
Publication Fund	3,000.00
Audubon Fund	2,500.00
Esther Herrman Research Fund	10,000.00
John Strong Newberry Fund	1,000.00
Income Permanent Fund..	1,860.03
Income Audubon Fund....	591.83
Income Esther Herrman Fund	1,396.27
Income Newberry Fund...	277.19
<hr/>	
	\$43,637.89

		<i>Cost</i>
Lampe Mortgage.....	at 5 per cent..	\$12,000.00
Deane-Brennan Mortgage.....	at 5½ per cent..	4,036.67
4 Detroit City Gas Company's bonds.....	at 5 per cent..	4,000.00
3 Grand Rapids Gas Light Company's bonds.....	at 5 per cent..	2,910.00
10 Madison Gas and Electric Company's bonds....	at 6 per cent..	10,400.00
1 Binghamton Gas and Electric Company's bond..	at 5 per cent..	995.00
1 Quebec-Jacques Cartier Electric Company's bond.	at 5 per cent..	965.00
1 San Antonio Gas and Electric Company's bond..	at 5 per cent..	487.50
1 San Antonio Traction Company's bond.....	at 5 per cent..	487.50
5 U. S. Steel Corporation bonds.....	at 5 per cent..	5,081.25
Participation bond of Lawyers' Mortgage Co.....	at 5 per cent..	1,000.00
		<hr/>
		\$42,362.92

¹ Reduced from \$5,200 by part payment of \$1,163.33.

THE ORGANIZATION OF THE NEW YORK ACADEMY OF SCIENCES

THE ORIGINAL CHARTER

AN ACT TO INCORPORATE THE LYCEUM OF NATURAL HISTORY IN THE CITY OF NEW YORK

Passed April 20, 1818

WHEREAS, The members of the Lyceum of Natural History have petitioned for an act of incorporation, and the Legislature, impressed with the importance of the study of Natural History, as connected with the wants, the comforts and the happiness of mankind, and conceiving it their duty to encourage all laudable attempts to promote the progress of science in this State—therefore,

1. *Be it enacted by the People of the State of New York represented in Senate and Assembly*, That Samuel L. Mitchill, Casper W. Eddy, Frederick C. Schaeffer, Nathaniel Paulding, William Cooper, Benjamin P. Kissam, John Torrey, William Cumberland, D'Jurco V. Knevels, James Clements and James Pierce, and such other persons as now are, and may from time to time become members, shall be, and hereby are constituted a body corporate and politic, by the name of LYCEUM OF NATURAL HISTORY IN THE CITY OF NEW YORK, and that by that name they shall have perpetual succession, and shall be persons capable of suing and being sued, pleaded and being impleaded, answering and being answered unto, defending and being defended, in all courts and places whatsoever; and may have a common seal, with power to alter the same from time to time; and shall be capable of purchasing, taking, holding, and enjoying to them and their successors, any real estate in fee simple or otherwise, and any goods, chattels, and personal estate, and of selling, leasing, or otherwise disposing of said real or personal estate, or any part thereof, at their will and pleasure: *Provided always*, that the clear annual value or income of such real or personal estate shall not exceed the sum of five thousand dollars: *Provided*, however, that the funds of the said Corporation shall be used and appropriated to the promotion of the objects stated in the preamble to this act, and those only.

2. *And be it further enacted*, That the said Society shall from time to time, forever hereafter, have power to make, constitute, ordain, and establish such by-laws and regulations as they shall judge proper, for the elec-

tion of their officers; for prescribing their respective functions, and the mode of discharging the same; for the admission of new members; for the government of the officers and members thereof; for collecting annual contributions from the members towards the funds thereof; for regulating the times and places of meeting of the said Society; for suspending or expelling such members as shall neglect or refuse to comply with the by-laws or regulations, and for the managing or directing the affairs and concerns of the said Society: *Provided* such by-laws and regulations be not repugnant to the Constitution and laws of this State or of the United States.

3. *And be it further enacted*, That the officers of the said Society shall consist of a President and two Vice-Presidents, a Corresponding Secretary, a Recording Secretary, a Treasurer, and five Curators, and such other officers as the Society may judge necessary; who shall be annually chosen, and who shall continue in office for one year, or until others be elected in their stead; that if the annual election shall not be held at any of the days for that purpose appointed, it shall be lawful to make such election at any other day; and that five members of the said Society, assembling at the place and time designated for that purpose by any by-law or regulation of the Society, shall constitute a legal meeting thereof.

4. *And be it further enacted*, That Samuel L. Mitchill shall be the President; Casper W. Eddy the First Vice-President; Frederick C. Schaeffer the Second Vice-President; Nathaniel Paulding, Corresponding Secretary; William Cooper, Recording Secretary; Benjamin P. KISSAM, Treasurer, and John Torrey, William Cumberland, D'Jurco V. Knevels, James Clements, and James Pierce, Curators; severally to be the first officers of the said Corporation, who shall hold their respective offices until the twenty-third day of February next, and until others shall be chosen in their places.

5. *And be it further enacted*, That the present Constitution of the said Association shall, after passing of this Act, continue to be the Constitution thereof; and that no alteration shall be made therein, unless by a vote to that effect of three-fourths of the resident members, and upon the request in writing of one-third of such resident members, and submitted at least one month before any vote shall be taken thereupon.

State of New York, Secretary's Office.

I CERTIFY the preceding to be a true copy of an original Act of the Legislature of this State, on file in this Office.

ARCH'D CAMPBELL,

Dep. Sec'y.

ALBANY, April 29, 1818.

ORDER OF COURT

ORDER OF THE SUPREME COURT OF THE STATE OF NEW YORK
TO CHANGE THE NAME OF

THE LYCEUM OF NATURAL HISTORY IN THE CITY OF
NEW YORK

TO

THE NEW YORK ACADEMY OF SCIENCES

WHEREAS, in pursuance of the vote and proceedings of this Corporation to change the corporate name thereof from "The Lyceum of Natural History in the City of New York" to "The New York Academy of Sciences," which vote and proceedings appear to record, an application has been made in behalf of said Corporation to the Supreme Court of the State of New York to legalize and authorize such change, according to the statute in such case provided, by Chittenden & Hubbard, acting as the attorneys of the Corporation, and the said Supreme Court, on the 5th day of January, 1876, made the following order upon such application in the premises, viz:

At a special term of the Supreme Court of the State of New York, held at the Chambers thereof, in the County Court House, in the City of New York, the 5th day of January, 1876:

Present—HON. GEO. C. BARRETT, *Justice*.

In the matter of the application of
the Lyceum of Natural History
in the City of New York to au-
thorize it to assume the corporate
name of the New York Academy
of Sciences.

On reading and filing the petition of the Lyceum of Natural History in the City of New York, duly verified by John S. Newberry, the President and chief officer of said Corporation, to authorize it to assume the corporate name of the New York Academy of Sciences, duly setting forth

the grounds of said application, and on reading and filing the affidavit of Geo. W. Quackenbush, showing that notice of such application had been duly published for six weeks in the State paper, to wit, *The Albany Evening Journal*, and the affidavit of David S. Owen, showing that notice of such application has also been duly published in the proper newspaper of the County of New York, in which county said Corporation had its business office, to wit, in *The Daily Register*, by which it appears to my satisfaction that such notice has been so published, and on reading and filing the affidavits of Robert H. Browne and J. S. Newberry, thereunto annexed, by which it appears to my satisfaction that the application is made in pursuance of a resolution of the managers of said Corporation to that end named, and there appearing to me to be no reasonable objection to said Corporation so changing its name as prayed in said petition: Now on motion of Grosvenor S. Hubbard, of Counsel for Petitioner, it is

Ordered, That the Lyceum of Natural History in the City of New York be and is hereby authorized to assume the corporate name of The New York Academy of Sciences.

Indorsed: Filed January 5, 1876,

A copy.

WM. WALSH, *Clerk*.

Resolution of THE ACADEMY, accepting the order of the Court, passed February 21, 1876

And whereas, The order hath been published as therein required, and all the proceedings necessary to carry out the same have been had, Therefore:

Resolved, That the foregoing order be and the same is hereby accepted and adopted by this Corporation, and that in conformity therewith the corporate name thereof, from and after the adoption of the vote and resolution herein above referred to, be and the same is hereby declared to be THE NEW YORK ACADEMY OF SCIENCES.

AMENDED CHARTER

MARCH 19, 1902

CHAPTER 181 OF THE LAWS OF 1902

AN ACT to amend chapter one hundred and ninety-seven of the laws of eighteen hundred and eighteen, entitled "An act to incorporate the Lyceum of Natural History in the City of New York," a Corporation now known as The New York Academy of Sciences and to extend the powers of said Corporation.

(Became a law March 19, 1902, with the approval of the Governor. Passed, three-fifths being present.)

The People of the State of New York, represented in Senate and Assembly, do enact as follows:

SECTION I. The Corporation incorporated by chapter one hundred and ninety-seven of the laws of eighteen hundred and eighteen, entitled "An act to incorporate the Lyceum of Natural History in the City of New York," and formerly known by that name, but now known as The New York Academy of Sciences through change of name pursuant to order made by the supreme court at the city and county of New York, on January fifth, eighteen hundred and seventy-six, is hereby authorized and empowered to raise money for, and to erect and maintain, a building in the city of New York for its use, and in which also at its option other scientific societies may be admitted and have their headquarters upon such terms as said Corporation may make with them, portions of which building may be also rented out by said Corporation for any lawful uses for the purposes of obtaining income for the maintenance of such building and for the promotion of the objects of the Corporation; to establish, own, equip, and administer a public library, and a museum having especial reference to scientific subjects; to publish communications, transactions, scientific works, and periodicals; to give scientific instruction by lectures or otherwise; to encourage the advancement of scientific research and discovery, by gifts of money, prizes, or other assistance thereto. The building, or rooms, of said Corporation in the City of New York used exclusively for library or scientific purposes shall be subject to the provisions and be entitled to the benefits of subdivision seven of section four of chapter nine hundred and eight of the laws of eighteen hundred and ninety-six, as amended.

SECTION II. The said Corporation shall from time to time forever hereafter have power to make, constitute, ordain, and establish such by-laws and regulations as it shall judge proper for the election of its officers; for prescribing their respective functions, and the mode of discharging the same; for the admission of new members; for the government of officers and members thereof; for collecting dues and contributions towards the funds thereof; for regulating the times and places of meeting of said Corporation; for suspending or expelling such members as shall neglect or refuse to comply with the by-laws or regulations, and for managing or directing the affairs or concerns of the said Corporation: and may from time to time alter or modify its constitution, by-laws, rules, and regulations.

SECTION III. The officers of the said Corporation shall consist of a president and two or more vice-presidents, a corresponding secretary, a recording secretary, a treasurer, and such other officers as the Corporation may judge necessary; who shall be chosen in the manner and for the terms prescribed by the constitution of the said Corporation.

SECTION IV. The present constitution of the said Corporation shall, after the passage of this act, continue to be the constitution thereof until amended as herein provided. Such constitution as may be adopted by a vote of not less than three-quarters of such resident members and fellows of the said New York Academy of Sciences as shall be present at a meeting thereof, called by the Recording Secretary for that purpose, within forty days after the passage of this act, by written notice duly mailed, postage prepaid, and addressed to each fellow and resident member at least ten days before such meeting, at his last known place of residence, with street and number when known, which meeting shall be held within three months after the passage of this act, shall be thereafter the constitution of the said New York Academy of Sciences, subject to alteration or amendment in the manner provided by such constitution.

SECTION V. The said Corporation shall have power to consolidate, to unite, to co-operate, or to ally itself with any other society or association in the city of New York organized for the promotion of the knowledge or the study of any science, or of research therein, and for this purpose to receive, hold, and administer real and personal property for the uses of such consolidation, union, co-operation, or alliance subject to such terms and regulations as may be agreed upon with such associations or societies.

SECTION VI. This act shall take effect immediately.

STATE OF NEW YORK,

OFFICE OF THE SECRETARY OF STATE.

I have compared the preceding with the original law on file in this office, and do hereby certify that the same is a correct transcript therefrom, and the whole of said original law.

Given under my hand and the seal of office of the Secretary of State, at the city of Albany, this eighth day of April, in the year one thousand nine hundred and two.

JOHN T. McDONOUGH,
Secretary of State.

CONSTITUTION

ADOPTED, APRIL 24, 1902, AND AMENDED AT SUBSEQUENT TIMES

ARTICLE I. The name of this Corporation shall be The New York Academy of Sciences. Its object shall be the advancement and diffusion of scientific knowledge, and the center of its activities shall be in the City of New York.

ARTICLE II. The Academy shall consist of five classes of members, namely: Active Members, Fellows, Associate Members, Corresponding Members and Honorary Members. Active Members shall be the members of the Corporation who live in or near the City of New York, or who, having removed to a distance, desire to retain their connection with the Academy. Fellows shall be chosen from the Active Members in virtue of their scientific attainments. Corresponding and Honorary Members shall be chosen from among persons who have attained distinction in some branch of science. The number of Corresponding Members shall not exceed two hundred, and the number of Honorary Members shall not exceed fifty.

ARTICLE III. None but Fellows and Active Members who have paid their dues up to and including the last fiscal year shall be entitled to vote or to hold office in the Academy.

ARTICLE IV. The officers of the Academy shall be a President, as many Vice-Presidents as there are sections of the Academy, a Corresponding Secretary, a Recording Secretary, a Treasurer, a Librarian, an Editor, six elected Councilors and one additional Councilor from each allied society or association. The annual election shall be held on the third Monday in December, the officers then chosen to take office at the first meeting in January following.

There shall also be elected at the same time a Finance Committee of three.

ARTICLE V. The officers named in Article IV shall constitute a Council, which shall be the executive body of the Academy with general control over its affairs, including the power to fill *ad interim* any vacancies that may occur in the offices. Past Presidents of the Academy shall be *ex-officio* members of the Council.

ARTICLE VI. Societies organized for the study of any branch of science may become allied with the New York Academy of Sciences by consent of the Council. Members of allied societies may become Active Members of the Academy by paying the Academy's annual fee, but as

members of an allied society they shall be Associate Members with the rights and privileges of other Associate Members, except the receipt of its publications. Each allied society shall have the right to delegate one of its members, who is also an Active Member of the Academy, to the Council of the Academy, and such delegate shall have all the rights and privileges of other Councilors.

ARTICLE VII. The President and Vice-Presidents shall not be eligible to more than one re-election until three years after retiring from office; the Secretaries and Treasurer shall be eligible to re-election without limitation. The President, Vice-Presidents and Secretaries shall be Fellows. The terms of office of elected Councilors shall be three years, and these officers shall be so grouped that two, at least one of whom shall be a Fellow, shall be elected and two retired each year. Councilors shall not be eligible to re-election until after the expiration of one year.

ARTICLE VIII. The election of officers shall be by ballot, and the candidates having the greatest number of votes shall be declared duly elected.

ARTICLE IX. Ten members, the majority of whom shall be Fellows, shall form a quorum at any meeting of the Academy at which business is transacted.

ARTICLE X. The Academy shall establish by-laws, and may amend them from time to time as therein provided.

ARTICLE XI. This Constitution may be amended by a vote of not less than three-fourths of the Fellows and three-fourths of the active members present and voting at a regular business meeting of the Academy, provided that such amendment shall be publicly submitted in writing at the preceding business meeting, and provided also that the Recording Secretary shall send a notice of the proposed amendment at least ten days before the meeting, at which a vote shall be taken, to each Fellow and Active Member entitled to vote.

BY-LAWS

AS ADOPTED, OCTOBER 6, 1902, AND AMENDED AT SUBSEQUENT TIMES

CHAPTER I

OFFICERS

1. *President.* It shall be the duty of the President to preside at the business and special meetings of the Academy; he shall exercise the customary duties of a presiding officer.

2. *Vice-Presidents.* In the absence of the President, the senior Vice-President, in order of Fellowship, shall act as the presiding officer.

3. *Corresponding Secretary.* The Corresponding Secretary shall keep a corrected list of the Honorary and Corresponding Members, their titles and addresses, and shall conduct all correspondence with them. He shall make a report at the Annual Meeting.

4. *Recording Secretary.* The Recording Secretary shall keep the minutes of the Academy proceedings; he shall have charge of all documents belonging to the Academy, and of its corporate seal, which he shall affix and attest as directed by the Council; he shall keep a corrected list of the Active Members and Fellows, and shall send them announcements of the Meetings of the Academy; he shall notify all Members and Fellows of their election, and committees of their appointment; he shall give notice to the Treasurer and to the Council of matters requiring their action, and shall bring before the Academy business presented by the Council. He shall make a report at the Annual Meeting.

5. *Treasurer.* The Treasurer shall have charge, under the direction of the Council, of all moneys belonging to the Academy, and of their investment. He shall receive all fees, dues and contributions to the Academy, and any income that may accrue from property or investment; he shall report to the Council at its last meeting before the Annual Meeting the names of members in arrears; he shall keep the property of the Academy insured, and shall pay all debts against the Academy the discharge of which shall be ordered by the Council. He shall report to the Council from time to time the state of the finances, and at the Annual Meeting shall report to the Academy the receipts and expenditures for the entire year.

6. *Librarian.* The Librarian shall have charge of the library, under the general direction of the Library Committee of the Council, and shall conduct all correspondence respecting exchanges of the Academy. He shall make a report on the condition of the library at the Annual Meeting.

7. *Editor.* The editor shall have charge of the publications of the Academy, under the general direction of the Publication Committee of the Council. He shall make a report on the condition of the publications at the Annual Meeting.

CHAPTER II

COUNCIL

1. *Meetings.* The Council shall meet once a month, or at the call of the President. It shall have general charge of the affairs of the Academy.

2. *Quorum.* Five members of the Council shall constitute a quorum.

3. *Officers.* The President, Vice-Presidents and Recording Secretary of the Academy shall hold the same offices in the Council.

4. *Committees.* The Standing Committees of the Council shall be: (1) an Executive Committee consisting of the President, Treasurer, and Recording Secretary; (2) a Committee on Publication; (3) a Committee on the Library, and such other committees as from time to time shall be authorized by the Council. The action of these committees shall be subject to revision by the Council.

CHAPTER III

FINANCE COMMITTEE

The Finance Committee of the Academy shall audit the Annual Report of the Treasurer, and shall report on financial questions whenever called upon to do so by the Council.

CHAPTER IV

ELECTIONS

1. *Active Members.* (a) Active Members shall be nominated in writing to the Council by at least two Active Members or Fellows. If approved by the Council, they may be elected at the succeeding business meeting.

(b) Any Active Member who, having removed to a distance from the city of New York, shall nevertheless express a desire to retain his connection with the Academy, may be placed by vote of the Council on a list of Non-Resident Members. Such members shall relinquish the full privileges and obligations of Active Members. (*Vide* Chapters V and X.)

2. *Associate Members.* Workers in science may be elected to Associate Membership for a period of two years in the manner prescribed for Active Members. They shall not have the power to vote and shall not be eligible to election as Fellows, but may receive the publications. At any time subsequent to their election they may assume the full privileges of Active Members by paying the dues of such Members.

3. *Fellows, Corresponding Members and Honorary Members.* Nominations for Fellows, Corresponding Members and Honorary Members may be made in writing either to the Recording Secretary or to the Council at its meeting prior to the Annual Meeting. If approved by the Council, the nominees shall then be balloted for at the Annual Meeting.

4. *Officers.* Nominations for Officers, with the exception of Vice-Presidents, may be sent in writing to the Recording Secretary, with the name of the proposer, at any time not less than thirty days before the Annual Meeting. Each section of the Academy shall nominate a candi-

date for Vice-President, who, on election, shall be Chairman of the section; the names of such nominees shall be sent to the Recording Secretary properly certified by the sectional secretaries, not less than thirty days before the Annual Meeting. The Council shall then prepare a list which shall be the regular ticket. This list shall be mailed to each Active Member and Fellow at least one week before the Annual Meeting. But any Active Member or Fellow entitled to vote shall be entitled to prepare and vote another ticket.

CHAPTER V

DUES

1. *Dues.* The annual dues of Active Members and Fellows shall be \$10, payable in advance at the time of the Annual Meeting; but new members elected after May 1, shall pay \$5 for the remainder of the fiscal year.

The annual dues of elected Associate Members shall be \$3, payable in advance at the time of the Annual Meeting.

Non-Resident Members shall be exempt from dues, so long as they shall relinquish the privileges of Active Membership. (*Vide* Chapter X.)

2. *Members in Arrears.* If any Active Member or Fellow whose dues remain unpaid for more than one year, shall neglect or refuse to pay the same within three months after notification by the Treasurer, his name may be erased from the rolls by vote of the Council. Upon payment of his arrears, however, such person may be restored to Active Membership or Fellowship by vote of the Council.

3. *Renewal of Membership.* Any Active Member or Fellow who shall resign because of removal to a distance from the city of New York, or any Non-Resident Member, may be restored by vote of the Council to Active Membership or Fellowship at any time upon application.

CHAPTER VI

PATRONS, DONORS AND LIFE MEMBERS

1. *Patrons.* Any person contributing at one time \$1,000 to the general funds of the Academy shall be a Patron and, on election by the Council, shall enjoy all the privileges of an Active Member.

2. *Donors.* Any person contributing \$50 or more annually to the general funds of the Academy shall be termed a Donor and, on election by the Council, shall enjoy all the privileges of an Active Member.

3. *Life Members.* Any Active Member or Fellow contributing at one time \$100 to the general funds of the Academy shall be a Life Member

and shall thereafter be exempt from annual dues; and any Active Member or Fellow who has paid annual dues for twenty-five years or more may, upon his written request, be made a life member and be exempt from further payment of dues.

CHAPTER VII

SECTIONS

1. *Sections.* Sections devoted to special branches of Science may be established or discontinued by the Academy on the recommendation of the Council. The present sections of the Academy are the Section of Astronomy, Physics and Chemistry, the Section of Biology, the Section of Geology and Mineralogy and the Section of Anthropology and Psychology.

2. *Organization.* Each section of the Academy shall have a Chairman and a Secretary, who shall have charge of the meetings of their Section. The regular election of these officers shall take place at the October or November meeting of the section, the officers then chosen to take office at the first meeting in January following.

3. *Affiliation.* Members of scientific societies affiliated with the Academy, and members of the Scientific Alliance, or men of science introduced by members of the Academy, may attend the meetings and present papers under the general regulations of the Academy.

CHAPTER VIII

MEETINGS

1. *Business Meetings.* Business meetings of the Academy shall be held on the first Monday of each month from October to May inclusive.

2. *Sectional Meetings.* Sectional meetings shall be held on Monday evenings from October to May inclusive, and at such other times as the Council may determine. The sectional meeting shall follow the business meeting when both occur on the same evening.

3. *Annual Meeting.* The Annual Meeting shall be held on the third Monday in December.

4. *Special Meetings.* A special meeting may be called by the Council, provided one week's notice be sent to each Active Member and Fellow, stating the object of such meeting.

CHAPTER IX

ORDER OF BUSINESS

1. *Business Meetings.* The following shall be the order of procedure at business meetings:

1. Minutes of the previous business meeting.
2. Report of the Council.
3. Reports of Committees.
4. Elections.
5. Other business.

2. *Sectional Meetings.* The following shall be the order of procedure at sectional meetings:

1. Minutes of the preceding meeting of the section.
2. Presentation and discussion of papers.
3. Other scientific business.

3. *Annual Meetings.* The following shall be the order of procedure at Annual Meetings:

1. Annual reports of the Corresponding Secretary, Recording Secretary, Treasurer, Librarian, and Editor.
2. Election of Honorary Members, Corresponding Members, and Fellows.
3. Election of officers for the ensuing year.
4. Annual address of the retiring President.

CHAPTER X

PUBLICATIONS

1. *Publications.* The established publications of the Academy shall be the *Annals* and the *Memoirs*. They shall be issued by the Editor under the supervision of the Committee on Publications.

2. *Distribution.* One copy of all publications shall be sent to each Patron, Life Member, Active Member and Fellow; *provided*, that upon inquiry by the Editor such Members or Fellows shall signify their desire to receive them.

3. *Publication Fund.* Contributions may be received for the publication fund, and the income thereof shall be applied toward defraying the expenses of the scientific publications of the Academy.

CHAPTER XI

GENERAL PROVISIONS

1. *Debts.* No debts shall be incurred on behalf of the Academy, unless authorized by the Council.

2. *Bills.* All bills submitted to the Council must be certified as to correctness by the officers incurring them.

3. *Investments.* All the permanent funds of the Academy shall be invested in United States or in New York State securities or in first mortgages on real estate, provided they shall not exceed sixty-five per cent. of the value of the property, or in first-mortgage bonds of corporations which have paid dividends continuously on their common stock for a period of not less than five years. All income from patron's fees, life-membership fees and donor's fees shall be added to the permanent fund.

4. *Expulsion, etc.* Any Member or Fellow may be censured, suspended or expelled for violation of the Constitution or By-Laws, or for any offence deemed sufficient, by a vote of three-fourths of the Members and three-fourths of the Fellows present at any business meeting, provided such action shall have been recommended by the Council at a previous business meeting, and also, that one month's notice of such recommendation and of the offence charged shall have been given the Member accused.

5. *Changes in By-Laws.* No alteration shall be made in these By-Laws unless it shall have been submitted publicly in writing at a business meeting, shall have been entered on the Minutes with the names of the Members or Fellows proposing it, and shall be adopted by two-thirds of the Members and Fellows present and voting at a subsequent business meeting.

MEMBERSHIP OF THE
NEW YORK ACADEMY OF SCIENCES
HONORARY MEMBERS

31 DECEMBER, 1914

ELECTED.

- 1912. FRANK D. ADAMS, Montreal, Canada.
- 1898. ARTHUR AUWERS, Berlin, Germany.¹
- 1889. CHARLES BARROIS, Lille, France.
- 1907. WILLIAM BATESON, Cambridge, England.
- 1910. THEODOR BOVERI, Würzburg, Germany.
- 1901. CHARLES VERNON BOYS, London, England.
- 1904. W. C. BRÖGGER, Christiania, Norway.
- 1876. W. BOYD DAWKINS, Manchester, England.
- 1913. CHARLES DÉPERET, Lyons, France.
- 1902. Sir JAMES DEWAR, Cambridge, England.
- 1901. EMIL FISCHER, Berlin, Germany.
- 1876. Sir ARCHIBALD GEIKIE, Haslemere, Surrey, England.
- 1901. JAMES GEIKIE, Edinburgh, Scotland.
- 1898. Sir DAVID GILL, London, England.
- 1909. K. F. GÖBEL, Munich, Germany.
- 1889. GEORGE LINCOLN GOODALE, Cambridge, Mass.
- 1909. PAUL VON GROTH, Munich, Germany.
- 1894. ERNST HÄCKEL, Jena, Germany.
- 1912. GEORGE E. HALE, Mt. Wilson, Calif.
- 1899. JULIUS HANN, Vienna, Austria.
- 1898. GEORGE W. HILL, West Nyack, N. Y.
- 1896. AMBROSIUS A. W. HUBRECHT, Utrecht, Netherlands.
- 1896. FELIX KLEIN, Göttingen, Germany.
- 1909. ALFRED LACROIX, Paris, France.
- 1876. VIKTOR VON LANG, Vienna, Austria.
- 1898. E. RAY LANKESTER, London, England.
- 1880. Sir NORMAN LOCKYER, London, England.
- 1911. ERNST MACH, Munich, Germany.
- 1912. ILIYA METCHNIKOF, Paris, France.
- 1898. FRIDTJOF NANSEN, Christiania, Norway.
- 1908. WILHELM OSTWALD, Gross-Bothen, Germany.
- 1898. ALBRECHT PENCK, Berlin, Germany.

¹ Deceased.

ELECTED.

- 1898. WILHELM PFEFFER, Leipzig, Germany.
- 1900. EDWARD CHARLES PICKERING, Cambridge, Mass.
- 1911. EDWARD BAGNALL POULTON, Oxford, England.
- 1913. Sir DAVID PRAIN, Kew, England.
- 1901. Sir WILLIAM RAMSAY, London, England.
- 1899. Lord RAYLEIGH, Witham, Essex, England.
- 1898. HANS H. REUSCH, Christiania, Norway.
- 1887. Sir HENRY ENFIELD ROSCOE, London, England.
- 1912. SHO WATASÉ, Tokyo, Japan.
- 1904. KARL VON DEN STEINEN, Berlin, Germany.
- 1896. JOSEPH JOHN THOMSON, Cambridge, England.
- 1900. EDWARD BURNETT TYLOR, Oxford, England.
- 1904. HUGO DE VRIES, Amsterdam, Netherlands.
- 1907. JAMES WARD, Cambridge, England.
- 1904. WILHELM WUNDT, Leipzig, Germany.

CORRESPONDING MEMBERS

31 DECEMBER, 1914.

- 1883. CHARLES CONRAD ABBOTT, Trenton, N. J.
- 1891. JOSÉ G. AGUILERA, Mexico City, Mexico.
- 1890. WILLIAM DE WITT ALEXANDER, Honolulu, Hawaii.
- 1899. C. W. ANDREWS, London, England.
- 1876. JOHN HOWARD APPLETON, Providence, R. I.
- 1899. J. G. BAKER, Kew, England.
- 1898. ISAAC BAGLEY BALFOUR, Edinburgh, Scotland.
- 1878. ALEXANDER GRAHAM BELL, Washington, D. C.
- 1867. EDWARD L. BERTHOUD, Golden, Colo.
- 1897. HERBERT BOLTON, Bristol, England.
- 1899. G. A. BOULENGER, London, England.
- 1874. T. S. BRANDEGEE, Berkeley, Calif.
- 1884. JOHN C. BRANNER, Stanford University, Calif.
- 1894. BOHUSLAY BRAUNER, Prague, Bohemia.
- 1874. WILLIAM BREWSTER, Cambridge, Mass.
- 1898. T. C. CHAMBERLIN, Chicago, Ill.
- 1876. FRANK WIGGLESWORTH CLARKE, Washington, D. C.
- 1891. L. CLERC, Ekaterinburg, Russia.
- 1877. THEODORE B. COMSTOCK, Los Angeles, Calif.
- 1868. M. C. COOKE, London, England.
- 1876. H. B. CORNWALL, Princeton, N. J.

ELECTED.

- 1880. CHARLES B. CORY, Boston, Mass.
- 1877. JOSEPH CRAWFORD, Philadelphia, Pa.
- 1895. HENRY P. CUSHING, Cleveland, O.
- 1879. T. NELSON DALE, Pittsfield, Mass.
- 1870. WILLIAM HEALEY DALL, Washington, D. C.
- 1885. EDWARD SALISBURY DANA, New Haven, Conn.
- 1898. WILLIAM M. DAVIS, Cambridge, Mass.
- 1894. RUTHVEN DEANE, Chicago, Ill.
- 1890. ORVILLE A. DERBY, Rio de Janeiro, Brazil.
- 1899. LOUIS DOLLO, Brussels, Belgium.
- 1876. HENRY W. ELLIOTT, Lakewood, O.
- 1880. JOHN B. ELLIOTT, Tulane Univ., La.
- 1869. FRANCIS E. ENGELHARDT, Syracuse, N. Y.
- 1879. HERMAN LE ROY FAIRCHILD, Rochester, N. Y.
- 1879. FRIEDRICH BERNHARD FITTICA, Marburg, Germany.
- 1885. LAZARUS FLETCHER, London, England.
- 1899. EBERHARD FRAAS, Stuttgart, Germany.
- 1879. REINHOLD FRITZGARTNER, Tegucigalpa, Honduras.
- 1870. GROVE K. GILBERT, Washington, D. C.
- 1865. CHARLES A. GOESSMAN, Amherst, Mass.
- 1888. FRANK AUSTIN GOOCH, New Haven, Conn.
- 1868. C. R. GREENLEAF, San Francisco, Calif.
- 1883. Marquis ANTONIO DE GREGORIO, Palermo, Sicily.
- 1869. R. J. LECHMERE GUPPY, Trinidad, B. W. I.
- 1882. Baron ERNST VON HESSE-WARTEGG, Lucerne, Switzerland.
- 1867. C. H. HITCHCOCK, Honolulu, H. I.
- 1900. WILLIAM HENRY HOLMES, Washington, D. C.
- 1890. H. D. HOSKOLD, Buenos Ayres, Argentine Republic.
- 1896. J. P. IDDINGS, Brinklow, Md.
- 1875. MALVERN W. ILES, Dubuque, Ia.
- 1899. OTTO JÄKEL, Greifswald, Germany.
- 1876. DAVID STARR JORDAN, Stanford University, Calif.
- 1876. GEORGE A. KOENIG, Houghton, Mich.
- 1888. Baron R. KUKI, Tokyo, Japan.
- 1876. JOHN W. LANGLEY, Cleveland, O.
- 1876. S. A. LATTIMORE, Rochester, N. Y.
- 1894. WILLIAM LIBBEY, Princeton, N. J.
- 1899. ARCHIBALD LIVERSIDGE, London, England.
- 1876. GEORGE MACLOSKIE, Princeton, N. J.
- 1876. JOHN WILLIAM MALLET, Charlottesville, Va.

ELECTED.

- 1891. CHARLES RIBORG MANN, Chicago, Ill.
- 1867. GEORGE F. MATTHEW, St. John, N. B., Canada.
- 1874. CHARLES JOHNSON MAYNARD, West Newton, Mass.
- 1874. THEODORE LUQUEER MEAD, Oviedo, Fla.
- 1892. J. DE MENDIZÁBAL-TAMBORREL, Mexico City, Mexico.
- 1874. CLINTON HART MERRIAM, Washington, D. C.
- 1898. MANSFIELD MERRIAM, South Bethlehem, Pa.
- 1876. WILLIAM GILBERT MIXTER, New Haven, Conn.
- 1890. RICHARD MOLDENKE, Watchung, N. J.
- 1895. C. LLOYD MORGAN, Bristol, England.
- 1864. EDWARD S. MORSE, Salem, Mass.
- 1898. GEORGE MURRAY, London, England.
- . EUGEN NETTO, Giessen, Germany.
- 1866. ALFRED NEWTON, Cambridge, England.
- 1897. FRANCIS C. NICHOLAS, New York, N. Y.
- 1882. HENRY ALFRED ALFORD NICHOLLS, Dominica, B. W. I.
- 1880. EDWARD J. NOLAN, Philadelphia, Pa.
- 1876. JOHN M. ORDWAY, New Orleans, La.
- 1900. GEORGE HOWARD PARKER, Cambridge, Mass.
- 1876. STEPHEN F. PECKHAM, New York, N. Y.
- 1877. FREDERICK PRIME, Philadelphia, Pa.
- 1868. RAPHAEL PUMPELLY, Newport, R. I.
- 1876. B. ALEX. RANDALL, Philadelphia, Pa.
- 1876. IRA REMSEN, Baltimore, Md.
- 1874. ROBERT RIDGWAY, Washington, D. C.
- 1886. WILLIAM L. ROBB, Troy, N. Y.
- 1876. SAMUEL P. SADTLER, Philadelphia, Pa.
- 1899. D. MAX SCHLOSSER, Munich, Germany.
- 1898. W. B. SCOTT, Princeton, N. J.
- 1894. W. T. SEDGWICK, Boston, Mass.
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GENERAL INDEX TO VOLUME XXIV

Names of Authors and other Persons in **Heavy-face Type**

Titles of Papers in **SMALL CAPS**

- Abbott, C. G.**, Reference to, 42
Active Members, Election of, 347, 352, 362, 365, 377, 386, 396
Active Members, List of, 426
Agassiz, Louis, Reference to, 307
Aldrich, L. P., Reference to, 42
Alternations of elevation and climate during geological time, 173-174
Ameghino, Florentino, References to, 179, 193, 194, 196, 197, 198, 233, 258, 268, 270, 284, 315
AMERICAN EOCENE LEMURS (*Notharctus LEIDY*), **William K. Gregory** [Abstract], 383
American temperature data for 1900-1909, 73-87
Anderson, K., Reference to, 227
ANNUAL MEETING, MINUTES OF THE, Edmund Otis Hovey, 399
ANTIGORITE AND TALC, THE GENESIS OF, Alexis A. Julien, 23-38
Antigorite directly from olivine by hydration, The formation of, 26-28
Antigorite directly from olivine by thermal alteration, The formation of, 28-29
Antigorite, Direct hydration by agencies within two belts, 29-30
Antigorite, the genesis of, 26
Armour, Allison V., Active Member, 396
Arctic ice conditions, Temperature, variations and changes in the, 104-111
Arctowski, Henryk, **A STUDY OF THE CHANGES IN THE DISTRIBUTION OF TEMPERATURE IN EUROPE AND NORTH AMERICA DURING THE YEARS 1900-1909**, 39-113; [Title], 253
Arctowski, Henryk, **VOLCANIC DUST VEILS AND CLIMATIC VARIATIONS** [Abstract], 398
Arlt, Theodore, Reference to, 204
Arnold, James Loring, Active Member, 377
ASPECTS OF EMOTIONAL REACTION, SOME, Wayne P. Smith [Abstract], 389
Associate Members, Election of, 353, 365, 380, 386, 397
Associate Members, List of, 432
Avery, Ledyard, Active Member, 396
Baker, Hugh Potter, Active Member, 396
Baird, Charles, Active Member, 396
Barnes, H. T., **THE PHYSICAL EFFECTS PRODUCED BY ICEBERGS IN THE NORTH ATLANTIC** [Abstract], 356
Barrell, Joseph, Reference to, 181
BASE OF THE CRANIUM IN ANTHROPOIDS AND MAN, THE, William K. Gregory [Abstract], 349
Bates, —, Reference to, 212
Bean, C. Homer, **DEMONSTRATION OF PSYCHOLOGICAL APPARATUS** [Abstract], 394
Becke, F., Reference to, 27
Behrend, Otto F., Active Member, 396
Beller, William F., Active Member, 396
Benedict, Laura Watson, **A STUDY OF BAGOBO CEREMONIALS, MAGIC AND MYTH** [Title], 370
Berckhemmer, Fritz, **ON THE OCCURRENCE OF CALCAREOUS ALGÆ IN THE PALEOZOIC ROCKS OF NORTH AMERICA** [Abstract], 378
and **Francis M. van Tuyl**, **A PROBLEMATIC FOSSIL FROM THE CATSKILL FORMATION** [Abstract], 378

- Berkey, Charles P.**, MINUTES OF BUSINESS MEETING, 365
 Reference to, 118
 SYMPOSIUM ON PORTO RICO [Abstract], 399
 THE ORIGIN OF SOME OF THE COMPLEX STRUCTURES OF THE ANCIENT GNEISSES OF NEW YORK [Title], 348; [Abstract], 353, 367
- Bernstein, S. S.**, Active Member, 365
- Bewley, J.**, Reference to, 118
- Bickmore, A. S.**, Death of, 380
- Bigelow, Frank H.**, References to, 45, 46, 74, 102
- Bingham, Hiram**, RECENT EXPLORATION IN THE LAND OF THE INCAS [Abstract], 364
- BIOCHEMICAL STUDIES OF SELENIUM, **Victor E. Levine** [Abstract], 380
- Bird, Henry**, Active Member, 396
- Birds, Dispersal of, 292-294
- Bishop, Samuel H.**, Death of, 381
- BLACK SHALE PROBLEM, THE, A STUDY IN PALEOZOIC GEOGRAPHY, **A. W. Grabau** [Abstract], 378
- Blanford, —**, Reference to, 44
- Bliss, William H.**, Active Member, 396
- Boettger, Henry W.**, Death of, 353
- Bonney, T. G.**, References to, 27, 28
- BOOK OF NATURE, **Raymond L. Ditmars** [Title], 401
- Borst, Charles A.**, Reference to, 117
- Bowron, W. M.**, Reference to, 118
- Brauns, R.**, Reference to, 27
- Brigham, Carl C.**, AN EXPERIMENTAL CRITIQUE OF THE BINET-SIMON SCALE [Abstract], 359
- Britton, N. L.**, SYMPOSIUM ON PORTO RICO [Abstract], 369, 399
- Broili, F.**, Reference to, 295
- Broom, R.**, CRITIQUE OF KEITH'S AND SMITH WOODWARD'S RESTORATIONS OF THE PILTDOWN SKULL [Title], 349
 References to, 263, 264, 266, 269, 276
- Brückner, Edward**, Reference to, 44
- Buffon, G. L. L.**, Reference to, 179
- Burchard, E. F.**, Reference to, 117
- BUSINESS MEETINGS, MINUTES OF, **Charles P. Berkey**, 365
Edmund Otis Hovey, 347, 352, 362, 377, 380, 386, 395
 By-laws of the New York Academy of Sciences, 414
- Cactocrinus baccatus* sp. nov., 4
cœlatus var. *spinotentaculus* (Hall), 13
denticulatus, Wachsmuth and Springer, 7
limabrachiatus (Hall), 14
multibrachiatus (Hall), 12
opusculus (Hall), 8
platybrachiatus sp. nov., 5
proboscidalis (Hall), 3
reticulatus (Hall), 6
 Wachsmuth and Springer, 3
- Camarasaurus* COPE, NOTES ON, **C. C. Mook**, 19-22
- CAT, DEVELOPMENT OF THE NEURAXIS IN THE DOMESTIC, TO THE STAGE OF TWENTY-ONE SOMITES, **H. von W. Schulte** and **Frederick Tilney**, 319-346
- Chamberlin, T. C.**, References to, 128, 137, 173, 174, 176, 304
- CHIMNEYHILL FORMATION OF OKLAHOMA, THE OÖLITES OF THE, **Chester A. Reeds** [Title], 348
- Chrysotile and retinalite, Genesis of, 33-35
- Cirkel, F.**, Reference to, 36
- Clarke, F. W.**, cited, 24, 27
- Clayton, H. Helm**, References to, 42, 73, 74
- CLIMATE AND EVOLUTION, **W. D. Matthew**, 171-318
- Cole, Fay Cooper**, THE WILD TRIBES OF MINDANAO [Abstract], 352
- COMPARISON OF THE EFFECTS OF STRYCHNINE AND CAFFEINE ON MENTAL AND MOTOR EFFICIENCY, **A. T. Poffenberger** [Abstract], 359
- COMPARISON OF STYLUS AND KEY IN THE TAPPING TEST, **A. H. L. Hollingworth** [Abstract], 359

CONFERENCE ON THE PILTDOWN SKULL AND THE ORIGIN OF MAN, **Henry Fairfield Osborn**, **J. Leon Williams**, **R. Broom**, **William K. Gregory** [Abstract], 349

Constitution of the New York Academy of Sciences, 413

Cooper, —, Reference to, 271

Cope, **Edward D.**, References to, 19, 20, 22

Cornu, **F.**, Reference to, 27

Corresponding Members, List of, 422

CORRESPONDING SECRETARY, REPORT OF THE. **Henry E. Crampton**, 401

Cossmann, —, Reference to, 193

Crampton, **Henry E.**, REPORT OF THE CORRESPONDING SECRETARY, 401
SYMPOSIUM ON PORTO RICO [Abstract], 369

CREATINE AND CREATININE, **Victor S. Meyers** [Title], 370

CRINOID ARMS IN STUDIES OF PHYLOGENY, THE USE OF, **Elvira Wood**, 1-17

CRITIQUE OF KEITH'S AND SMITH WOODWARD'S RESTORATIONS OF THE PILTDOWN SKULL, **R. Broom** [Title], 349

CULTURAL RELATIONS OF THE NORTHERN PAIUTE, THE, **Robert H. Lowie** [Abstract], 386

D'Achiardi, **A.**, Reference to, 27

Dall, **W. H.**, Reference to, 204

Daly, **Reginald A.**, PROBLEMS OF VOLCANIC ACTION [Abstract], 387

Dana, **J. D.**, References to, 27, 118

Darwin, **Charles**, References to, 183, 281
Deaths, 353, 362, 365, 377, 380, 381, 386, 397

Dederer, **Pauline H.**, References to, 266, 269

de la Torre, —, Reference to, 291

Delesse, —, cited, 23

References to, 25, 33

DEMONSTRATION OF PSYCHOLOGICAL APPARATUS. **C. Homer Bean** [Abstract], 394

Depéret, —, References to, 306, 317, 318

Deschere, **Harvey**, Active Member, 362

DEVELOPMENT AND ANATOMY OF THE SALIVARY GLANDS IN CERTAIN MAMMALIAN ORDERS, THE, **H. von W. Schulte** [Abstract], 363

DEVELOPMENT OF THE NEURAXIS IN THE DOMESTIC CAT TO THE STAGE OF TWENTY-ONE SOMITES, **H. von W. Schulte** and **Frederick Tilney**, 319-346

De Young, **Estelle**, IS THERE SUCH A THING AS GENERAL INGENUITY? [Abstract], 371

Dines, **J. S.**, Reference to, 104

Dispersal of amphibia, 294-296

birds, 292-294

fresh-water fishes, 297-299

mammalia, 299-274

reptilia, 274-292

Distribution of land and water, present and past, 175-176

Ditmars, **Raymond L.**, BOOK OF NATURE [Title], 401
Reference to, 287

Dodge, **Francis P.**, Active Member, 396

Doherty, **Henry L.**, REPORT OF THE TREASURER, 404

Dollo, **L.**, Reference to, 278

Douglass, **Earl**, References to, 270, 289

Dual processes in genesis of talc and antigorite, 30-33

Earle, **Raymond Bartlett**, THE GENESIS OF CERTAIN PALEOZOIC INTERBEDDED IRON ORE DEPOSITS, 115-170

SECTION OF GEOLOGY AND MINERALOGY, 366

EARLY STAGES IN THE DEVELOPMENT OF THE BRAIN IN THE DOMESTIC CAT, **H. von W. Schulte** [Abstract], 379

Ebelmen, —, Reference to, 28

Eccles, **R. G.**, Active Member, 347

Eckel, **E. C.**, cited, 126

References to, 117, 140

EDITOR, REPORT OF THE. **Edmund Otis Hovey**, 403

- Effects of alternations of elevation and climate upon evolution of terrestrial faunas, 176-178
- EFFICIENCY OF THE EYE UNDER DIFFERENT CONDITIONS OF LIGHTING, C. E. Ferree [Abstract], 384
- Eigenmann, C. H., References to, 297, 298
- ELEMENTARY FORMS AND PHENOMENA IN THE EVOLUTION OF VISUAL PERCEPTION, SOME, George T. Stevens [Abstract], 388
- EQUIVALENCE OF REPETITIONS FOR RECALL AND RECOGNITION, Edith F. Mulhall [Abstract], 373
- ETIOLOGICAL FACTORS OF MENTAL DEFICIENCY, SOME, Max G. Schlapp [Title], 371
- EVOLUTION, CLIMATE AND, W. D. Matthews, 171-318
- European temperature data for 1900-1909, 50-73
- EXPERIMENTAL CRITIQUE OF THE BINET-SIMON SCALE, AN, Carl C. Brigham [Abstract], 359
- EXPERIMENT VS. COURT DECISION, Richard H. Paynter [Abstract], 394
- Fassig, Oliver L., Reference to, 104
- Fellows, Election of, 400
- Felix, W., Reference to, 333
- Ferree, C. E., THE EFFICIENCY OF THE EYE UNDER DIFFERENT CONDITIONS OF LIGHTING [Abstract], 384
- Fine, Morris S., URIC ACID [Title], 370
- Finlay, George I., Fellow, 400
- Fisher, G. Clyde, Active Member, 396
- Fleischmann, A., Reference to, 333
- Foerste, A. F., cited, 131
- Formation of antigorite directly from olivine by hydration, 26-28
- Formation of antigorite from olivine by thermal alteration, 28-29
- Fowle, F. E., Reference to, 42
- Fraas, E., Reference to, 276
- Fresh-water fishes, Dispersal of, 297
- Gadow, Hans, cited, 288, 291, 313
References to, 290, 291, 295, 311, 312, 314, 316
- Gaudry, A., References to, 193, 198, 258, 318
- Gawthrop, Henry, Reference to, 74
- GEOLOGICAL AGE AND SUCCESSION OF EARLY HUMAN TYPES, Henry Fairfield Osborn [Title], 349
- GENESIS OF ANTIGORITE AND TALC, THE, Alexis A. Julien, 23-38; [Abstract], 367
- Genesis of antigorite and talc, Dual processes in, 30-33
- Genesis of antigorite, The, 26
- GENESIS OF CERTAIN PALEOZOIC INTERBEDDED IRON ORE DEPOSITS, THE, Raymond Bartlett Earle, 115-170
- Genesis of chrysotile and retinalite, 33-35
- Gidley, J. W., Reference to, 263
- Gill, Theo. N., Death of, 397
- Goldenweiser, A. A., Active Member, 352
ORIGINS OF CLANS AMONG THE IROQUOIS [Abstract], 384
- Gorczynski, L. H., Reference to, 60
- Granger, Walter, Reference to, 263
- Gregory, W. K., AN AMERICAN EOCENE LEMUR (*Notharctus* LEIDY) [Abstract], 383
OBSERVATIONS ON THE INDBISINÆ AND OTHER LEMURS [Abstract], 388
References to, 203, 226
SECTION OF BIOLOGY, 348, 355, 363, 369, 379, 382, 387, 398
THE BASE OF THE CRANIUM IN ANTHROPOIDS AND MAN [Abstract], 349
- Grabau, A. W., cited, 119
References to, 4, 118, 122
THE BLACK SHALE PROBLEM: A STUDY IN PALEOZOIC GEOGRAPHY [Abstract], 378
- Grimsley, G. P., cited, 128
- HABITS, ANATOMY AND RELATIONSHIPS OF THE SEA ELEPHANT (*Mirounga leonina*), Robert Cushman Murphy [Abstract], 355
- Hahn, F. F., Death of, 386

- Hann, J.**, Reference to, 75
Harris, Alfred, Active Member, 396
Hartnagel, C. A., cited, 127
Hatcher, J. B., References to, 193, 198
Haug, E., Reference to, 189
Hay, O. P., cited, 283
 References to, 256, 280, 281
Hayner, B. A., Active Member, 365
Hazen, George H., Active Member, 396
Heller, Samuel, Active Member, 396
Hellman, Milo, Active Member, 386
Hepites, S. C., Reference to, 60
Hildebrandsson, R. H., Reference to, 44
Hill, R. T., Reference to, 204
Hillebrand, S., Reference to, 24
His, —, References to, 334, 337, 338, 343
Holland, T. H., References to, 22, 28
Hollingworth, H. L., A COMPARISON OF
 STYLUS AND KEY IN THE TAPPING
 TEST [Abstract], 359
 THE LOGIC OF INTERMEDIATE STEPS
 [Abstract], 393
Honorary Members, List of, 421
Hovey, Edmund Otis, MINUTES OF BUSI-
 NESS MEETINGS, 347, 352, 362, 377,
 380, 386, 395
 MINUTES OF THE ANNUAL MEETING,
 399
 RECORDS OF MEETINGS OF THE NEW
 YORK ACADEMY OF SCIENCES, 347-
 406
 Reference to, 118
 REPORT OF THE EDITOR, 403
 REPORT OF THE RECORDING SECRE-
 TARY, 401
Howard, Luke, Reference to, 42
Howe, Marshall A., SYMPOSIUM ON
 PORTO RICO [Abstract], 399
Howes, Paul Griswold, Active Member,
 396
Humphreys, W. J., Reference to, 43
Hunt, T. S., cited, 25, 35
 References to, 28, 36
Huntington, Ellsworth, Reference to, 44
Huntington, George S., Fellow, 400
 THE ILIO-COLIC JUNCTION IN VERTE-
 BRATES FROM THE STANDPOINT OF
 TAXONOMY AND FUNCTION [Ab-
 stract], 363
Hutter, Karl, Death of, 377
Huxley, T. H., References to, 192, 301
 ILIO-COLIC JUNCTION IN VERTEBRATES
 FROM THE STANDPOINT OF TAXON-
 OMY AND FUNCTION, **George S.**
Huntington [Abstract], 363
 Imperfection of the geological record,
 183-185
 INDIVIDUAL DIFFERENCES IN JUDICIAL
 CAPACITY, **Lillian Walton** [Ab-
 stract], 375
 IONIZATION EQUILIBRIUM, **James Ken-**
dall [Abstract], 388
 IRON ORE DEPOSITS, THE GENESIS OF
 CERTAIN PALEOZOIC INTERBEDDED,
Raymond Bartlett Earle, 115-170
 IS THERE SUCH A THING AS GENERAL
 INGENUITY? **Estelle de Young**
 [Abstract], 371
 IS THERE SUCH A THING AS GENERAL
 JUDICIAL CAPACITY? **Mary Ross**
 [Abstract], 374
Jaekel, O., Reference to, 276
 JOHN BOYD THACHER PARK; THE HEL-
 DERBERG ESCARPMENT, THE, **George**
F. Kunz [Title], 366
Johnson, Alice J., Active Member, 396
Johnson, Douglas W., SECTION OF GEOL-
 OGY AND MINERALOGY, 377
 THE STABILITY OF THE ATLANTIC
 COAST [Title], 362
 TOPOGRAPHIC FEATURES OF WESTERN
 EUROPE AND THEIR INFLUENCE ON
 THE CAMPAIGN AGAINST FRANCE
 [Abstract], 381
Johnston, J. B., Reference to, 335
Jones, Dwight A., Death of, 253
Julien, Alexis A., THE GENESIS OF AN-
 TIGORITE AND TALC, 23-38; [Ab-
 stract], 367
Kemp, James F., SYMPOSIUM ON PORTO
 RICO [Abstract], 369
Kendall, James, IONIZATION EQUILIBRIUM
 [Abstract], 388
Kernan, John Devereux, Active Member,
 396

- Kimball, Herbert H.**, Reference to, 43
Kimball, J. P., cited, 131
King, Willford I., Reference to, 42
Knight, Samuel H., Associate Member, 386
Knowlton, Frank H., Reference to, 198
Kremser, —, Reference to, 44
Kunz, George F., THE JOHN BOYD THACHER PARK; THE HELDERBERG ESCARPMENT [Title], 366
 Note Regarding the long period of dry weather in North America, 381
Langeloth, J., Death of, 381
 LOGIC OF INTERMEDIATE STEPS, THE, H. L. Hollingworth [Abstract], 393
Lutz, Frank E., SYMPOSIUM ON PORTO RICO [Abstract], 399
Lacroix, L. A., Reference to, 23
Lee, Marguerite T., Active Member, 352
Lee, W. T., Reference to, 198
Levine, Victor E., BIOCHEMICAL STUDIES OF SELENIUM [Abstract], 380
Lewis, J. V., References to, 25, 28
 LIBRARIAN, REPORT OF THE, **Ralph W. Tower**, 403
Lindgren, W., cited, 28
 Reference to, 33
Lindsey, Edward, Active Member, 396
Lockyer, Sir Norman, References to, 44, 74, 102
Lockyer, William J. S., References to, 49, 102
Loeb, Mrs. Morris, Active Member, 396
 Long-range variations of temperature, 41-50
Lowie, Robert H., SECTION OF ANTHROPOLOGY AND PSYCHOLOGY, 351, 356, 364, 370, 384, 389
 THE CULTURAL RELATIONS OF THE NORTHERN PAIUTE [Abstract], 386
Lull, R. S., cited, 277
 References to, 276, 279
Lydekker, Richard, cited, 281
 References to, 185, 203, 282
McCallie, S. W., cited, 118, 119
 References to, 117, 118, 128
McClure, C. F. W., Reference to, 344
McComas, H. C., SOME TESTS OF EFFICIENCY IN TELEPHONE OPERATORS [Abstract], 357
McGregor, James Howard, Fellow, 400
McMillin, Emerson, Patron, 347
McMillin, Marion, Active Member, 396
 Mammalia, Dispersal of, 209-274
Marsh, O. C., Reference to, 276
Martin, D. S., A PECULIAR FORM OF RADIATED TOURMALINE FROM VIRGINIA [Abstract], 367
Matausch, Ignaz, Active Member, 396
Matheson, W. J., Active Member, 352
Matthew, W. D., CLIMATE AND EVOLUTION, 171-318
 NEW DISCOVERIES IN THE LOWER EOCENE MAMMALS [Abstract], 383
 Reference to, 22
 SOME REMARKABLE EXTINCT ANIMALS OF SOUTH AMERICA [Abstract], 355
Maxwell, H. V., Reference to, 118
Melander, G., Reference to, 60
Meinardus, Wm., Reference to, 44
 MECHANISM OF ENZYME ACTION, THE, D. D. van Slyck [Title], 380
Meek, Seth Eugene, Death of, 380
 Membership of the New York Academy of Sciences, 421-432
Merriam, J. C., References to, 261, 271
Merrill, G. P., References to, 27, 28, 30, 33
Meyers, Victor S., CREATINE AND CREATININE [Title], 370
Miller, Adam M., Active Member, 396
Millward, Russell Hastings, Active Member, 396
Milne, Clyde, Active Member, 396
Miner, Roy W., SYMPOSIUM ON PORTO RICO [Abstract], 399
Minot, Charles Sedgwick, Death of, 397
Mitchell, Wesley C., Active Member, 396
Monrow, W. S., STUDIES IN RECOGNITION [Title], 370
Mook, C. C., A STATISTICAL STUDY OF VARIATION IN *Spirifer mucronatus* [Abstract], 398
 NOTES ON *Camarasaurus* COPE, 19-22

- MORPHOLOGY OF THE FLOOR OF THE THIRD VENTRICLE IN CRANIATES, THE, Frederick Tilney** [Abstract], 379
- Mossman, R. C.**, Reference to, 44
- MOTOR-EMOTIONAL EXPRESSION OF AN INFANT, Garry C. Myers** [Abstract], 392
- MOTTLED TRIBES HILL LIMESTONE AND ITS BEARING ON THE ORIGIN OF DOLOMITE, THE, Francis M. van Tuyl** [Abstract], 378
- Mullhall, Edith F.**, EQUIVALENCE OF REPETITIONS FOR RECALL AND RECOGNITION [Abstract], 373
- Murphy, Robert Cushman**, Active Member, 396
- HABITS. ANATOMY AND RELATIONSHIPS OF THE SEA ELEPHANT (*Mirounga leonina*)** [Abstract], 355
- Murray, Sir John**, Death of, 365
- Myers, Garry C.**, A STUDY OF APPETITE [Abstract], 372
- RECALL IN RELATION TO RETENTION** [Abstract], 361
- MOTOR-EMOTIONAL EXPRESSION OF AN INFANT** [Abstract], 392
- Natural rafts and the probabilities of over-sea migration thereby, 206-208
- Neal, H. V.**, Reference to, 335
- Neumayer, L.**, cited, 335
- References to, 319, 329, 333, 335
- Newberry, J. S.**, Reference to, 128
- NEW DISCOVERIES IN THE LOWER EOCENE MAMMALS, W. D. Matthew** [Abstract], 383
- Newland, D. H.**, cited, 127, 151
- Nichols, John T.**, SYMPOSIUM ON PORTO RICO [Abstract], 390
- Non-Resident Members, List of, 432
- Nopsca, F.**, Reference to, 278
- NOTES ON *Camarasaurus* COPE, C. C. Mook**, 19-22
- Notman, Arthur**, Active Member, 396
- OBSERVATIONS ON THE INDRISINÆ AND OTHER LEMURS, William K. Gregory** [Abstract], 388
- Oceanic and continental islands, Faunal differences between, 202-206
- O'Connell, Marjorie**, A REVISION OF THE GENUS *Zaphrentis* [Abstract], 348
- Olmstead, Mrs. C. T.**, Death of, 362
- ON THE OCCURRENCE OF CALCAREOUS ALGÆ IN THE PALEOZOIC ROCKS OF NORTH AMERICA, Fritz Berckhemmer** [Abstract], 378
- OÖLITES OF THE CHIMNEYHILL FORMATION OF OKLAHOMA, THE, Chester A. Reeds** [Title], 348
- Organization of the New York Academy of Sciences, 407
- ORIGINS OF CLANS AMONG THE IROQUOIS, A. A. Goldenweiser** [Abstract], 384.
- ORIGIN OF DOLOMITES, THE, Francis M. van Tuyl** [Abstract], 362
- ORIGIN OF SOME OF THE COMPLEX STRUCTURES OF THE ANCIENT GNEISSES OF NEW YORK, THE, Charles P. Berkey** [Title], 348; [Abstract], 353, 367
- Ortmann, A.**, References to, 193, 198, 291, 301, 302, 315
- Osborn, Henry Fairfield**, GEOLOGICAL AGE AND SUCCESSION OF EARLY HUMAN TYPES [Title], 349
- References to, 20, 308, 314
- Pacini, A. B.**, Reference to, 117
- SECTION OF GEOLOGY AND MINERALOGY**, 347, 362, 381, 387, 397
- Pacini, Augustus**, Reference to, 117
- PALEOZOIC INTERBEDDED IRON ORE DEPOSITS, THE GENESIS OF CERTAIN, Raymond Bartlett Earle**, 115-170
- Patron, Election of, 347
- Patterson, T. H. Hoge**, Active Member, 396
- Paynter, Richard H.**, EXPERIMENT VS. COURT DECISION [Abstract], 394
- Perry, Charles J.**, Death of, 377
- Pfeffer, G.**, Reference to, 315
- Pavlow, —**, Reference to, 244

- Peale, A. C.**, Reference to, 198
PECULIAR FORM OF RADIATED TOURMALINE FROM VIRGINIA, A. D. S. **Martin** [Abstract], 367
 Permanency of the ocean basins, 174-175
Peterson, O. A., Reference to, 254
Pettigrew, David L., Death of, 353
Phalen, W. C., Reference to, 118
Phillips, Wm. B., References to, 140, 141
PHYLOGENY, THE USE OF CRINOID ARMS IN STUDIES OF, **Elvira Wood**, 1-17
PHYSICAL EFFECTS PRODUCED BY ICEBERGS IN THE NORTH ATLANTIC. THE, **H. T. Barnes** [Abstract], 356
Pike, F. H., Active Member, 347
Pilgrim, G. E., References to, 242, 249, 267, 271
PILTDOWN AND OTHER PREHISTORIC SKULLS, ON THE, **J. Leon Williams** [Title], 349
Piolti, G., Reference to, 27
Platt, J. B., Reference to, 344
Plough, Harold H., Associate Member, 397
Poffenberger, A. T., A COMPARISON OF THE EFFECTS OF STRYCHNINE AND CAFFEINE ON MENTAL AND MOTOR EFFICIENCY [Abstract], 359
Poor, Charles Lane, SYMPOSIUM ON PORTO RICO [Abstract], 369
Posepny, F., cited, 154
Pratt, J. H., References to, 25, 28
PROBLEMATIC FOSSIL FROM THE CATSKILL FORMATION. A, **Francis M. van Tuyl** and **Fritz Berckhemmer** [Abstract], 378
PROBLEMS OF VOLCANIC ACTION. Reginald A. Daly [Abstract], 387
Raeder, Ruth, Associate Member, 353
Baisin, C. A., Reference to, 27
Rathborne, B. C., Active Member, 396
RECALL IN RELATION TO RETENTION. Garry C. Myers [Abstract], 361
RECENT EXPLORATION IN THE LAND OF THE INCAS, **Hiram Bingham** [Abstract], 364
RECORDING SECRETARY, REPORT OF THE Edmund Otis Hovey, 401
RECORDS OF MEETINGS OF THE NEW YORK ACADEMY OF SCIENCES, Edmund Otis Hovey, 347-406
Redlich, K. A., Reference to, 27
Reeds, Chester A., **THE OÖLITES OF THE CHIMNEYHILL FORMATION OF OKLAHOMA** [Title], 348
Regan, Tate, Reference to, 304
REMARKABLE EXTINCT ANIMALS OF SOUTH AMERICA, SOME, **W. D. Matthew** [Abstract], 355
Reptilia, Dispersal of, 274-292
Retinalite, Genesis of chrysotile and, 33-35
 Review of the evolution of vertebrate life, 181-183
REVISION OF THE GENUS *Zaphrentis*, A. Marjorie O'Connell [Abstract], 348
Rogers, H. D., cited, 128
Rosenbusch, H., Death of, 380
 References to, 27, 28
Ross, Mary, **IS THERE SUCH A THING AS GENERAL JUDICIAL CAPACITY** [Abstract], 374
Both, J., cited, 26
 Reference to, 32
Both, Santiago, References to, 193, 197, 198, 199
Reiger, H. A., **TRANSFER AND INTERFERENCE IN THE SUBSTITUTION TEST** [Abstract], 358
Ruger, H. A., **SEX DIFFERENCES IN THE SOLUTION OF MECHANICAL PUZZLES** [Abstract], 376
Russell, H. C., Reference to, 49
Russell, I. C., cited, 129
 References to, 130, 137
Rutledge, J. J., cited, 130
Ryder, John A., Reference to, 22
Scharff, R. F., cited, 317
 References to, 303, 304, 305, 311, 314, 315, 316, 317
Schlapp, Max G., **SOME ETIOLOGICAL FACTORS OF MENTAL DEFICIENCY** [Title], 371

- licke, C. P.**, Active Member, 396
losser, Max, References to, 193, 199, 216, 242
neider, —, Reference to, 24
rauf, A., cited, 27
nuchert, Charles, Reference to, 190
nlte, Hermann von W., Active Member, 347
 EARLY STAGES IN THE DEVELOPMENT OF THE BRAIN IN THE DOMESTIC CAT [Abstract], 379
 Fellow, 400
 THE DEVELOPMENT AND ANATOMY OF THE SALIVARY GLANDS IN CERTAIN MAMMALIAN ORDERS [Abstract], 363
 and **Frederick Tilney**, DEVELOPMENT OF THE NEURAXIS IN THE DOMESTIC CAT TO THE STAGE OF TWENTY-ONE SOMITES, 319-346
weizer, —, Reference to, 23
ater, —, Reference to, 185
tt, W. B., References to, 193, 198, 231, 270
ibner, G. Hilton, Reference to, 179
 TION OF ANTHROPOLOGY AND PSYCHOLOGY, **Robert H. Lowie**, 351, 356, 364, 370, 384, 389
 TION OF ASTRONOMY, PHYSICS AND CHEMISTRY, **E. E. Smith**, 356, 370, 380, 384, 388
 TION OF BIOLOGY, **William K. Gregory**, 348, 353, 355, 363, 369, 379, 382, 387, 398
 TION OF GEOLOGY AND MINERALOGY, **R. B. Earle**, 366
D. W. Johnson, 377
A. B. Pacini, 347, 353, 362, 381, 387, 397
 K DIFFERENCES IN THE SOLUTION OF MECHANICAL PUZZLES, **H. A. Ruger** [Abstract], 376
aler, N. S., cited, 131
inner, Alanson, SOCIAL AND CEREMONIAL ORGANIZATIONS AND SOCIETIES OF THE IOWA INDIANS [Abstract], 385
ck, E. B., Active Member, 365
nton, T. W., Reference to, 193
Smith, Elliott, Reference to, 226
Smith, E. A., Reference to, 117
Smith, E. E., SECTION OF ASTRONOMY, PHYSICS AND CHEMISTRY, 356, 370, 380, 384, 388
Smith, Warren S., Associate Member, 380
Smith, Wayne P., SOME ASPECTS OF EMOTIONAL REACTIONS [Abstract], 389
Smyth, C. H., Jr., References to, 117, 118, 126, 127, 135, 136
 Silurian era, The, 118-120
Sinclair, W. J., References to, 261, 266
 SOCIAL AND CEREMONIAL ORGANIZATIONS AND SOCIETIES OF THE IOWA INDIANS, **Alanson Skinner** [Abstract], 385
Spencer, J. Selden, Death of, 397
Spencer, J. W., Reference to, 204
Springer, Frank, Reference to, 15
 STABILITY OF THE ATLANTIC COAST, THE, **Douglas W. Johnson** [Title], 362
 STARK EFFECT OR ELECTRIC RESOLUTION OF THE SPECTRA OF THE ELEMENTS, THE, **Reinhard A. Wetzel** [Title], 388
 STATISTICAL STUDY OF VARIATION IN *Spirifer mucronatus*, **C. C. Mook** [Abstract], 398
Stevenson, J. J., Reference to, 118
Stehlin, H. G., References to, 272, 308
Stevens, George T., SOME ELEMENTARY FORMS AND PHENOMENA IN THE EVOLUTION OF VISUAL PERCEPTION [Abstract], 388
Stockmann, Marie F. C., Active Member, 396
Stoeckel, Carl, Active Member, 396
Stone, I. Frank, Active Member, 396
Strong, O. S., THE THEORY OF NERVE COMPONENTS [Abstract], 379
 STUDIES IN RECOGNITION, **W. S. Monroe** [Title], 370
 STUDY OF APPETITE, **A. Garry C. Myers** [Abstract], 372
 STUDY OF BAGOB CEREMONIAL, MAGIC AND MYTH, **Laura Watson Benedict** [Title], 370

- STUDY OF THE CHANGES IN THE DISTRIBUTION OF TEMPERATURE IN EUROPE AND NORTH AMERICA DURING THE YEARS 1900-1909, **Henryk Arctowski**, 39-113; [Title], 353
- Suess, E.**, Reference to, 189
- SYMPOSIUM ON PORTO RICO, **James F. Kemp**, **Charles Lane Poor**, **Henry E. Crampton**, **N. L. Britton** [Abstract], 369
- Charles P. Berkey**, **N. L. Britton**, **Marshall A. Howe**, **N. Wille**, **Roy W. Miner**, **Frank E. Lutz**, **John T. Nichols** [Abstract], 399
- TALC, THE GENESIS OF ANTIGORITE AND, **Alexis A. Julien**, 23-38
- Taylor, George**, Death of, 353
- Teal, J. J. H.**, cited, 26
Reference to, 32
- Temperature curves for several stations in the United States. Consecutive, 97-104
- Temperature data for 1900-1909. American, 73, 87
- Temperature data for 1900-1909. European, 50-73
- TEMPERATURE IN EUROPE AND NORTH AMERICA DURING THE YEARS 1900-1909, A STUDY OF THE CHANGES IN THE DISTRIBUTION OF, **Henryk Arctowski**, 39-113
- Temperature, Long range variations of, 41-50
- Temperature variations and the changes in the arctic ice conditions, 104-111
- Tertiary correlation in South America, 195-200
- TESTS OF EFFICIENCY IN TELEPHONE OPERATORS. SOME, **H. C. McComas** [Abstract], 357
- THEORY OF NERVE COMPONENTS, THE, **O. S. Strong** [Abstract], 379
- Thévenin, A.**, Reference to, 306
- Thomas, Oldfield**, Reference to, 228
- Tilney, Frederick**, Active Member, 396
THE MORPHOLOGY OF THE FLOOR OF THE THIRD VENTRICLE IN CRANIATES [Abstract], 379
- Tilney, Frederick**, and **H. von Schulte**, DEVELOPMENT OF THE NEURAXIS IN THE DOMESTIC CAT TO THE STAGE OF TWENTY-ONE SOMITES, 319-346
- TOPOGRAPHIC FEATURES OF WESTERN EUROPE AND THEIR INFLUENCE ON THE CAMPAIGN AGAINST FRANCE, **Douglas W. Johnson** [Abstract], 381
- Tornier, —**, Reference to, 22
- Tower, Ralph W.**, REPORT OF THE LIBRARIAN, 403
- Townsend, C. H. T.**, Active Member, 396
- Trabert, W.**, Reference to, 60
- TRANSFER AND INTERFERENCE IN THE SUBSTITUTION TEST, **H. A. Ruger** [Abstract], 358
- TREASURER, REPORT OF THE, **Henry L. Doherty**, 404
- United States, Consecutive temperature curves for several stations in the, 97-104
- URIC ACID, **Morris S. Fine** [Title], 370
- USE OF CRINOID ARMS IN STUDIES OF PHYLOGENY, THE, **Elvira Wood**, 1-17
- Vanderbilt, F. W.**, Active Member, 396
- Van Hise, C. B.**, cited, 25, 29
- Van Slyck, D. D.**, THE MECHANISM OF ENZYME ACTION [Title], 380
- Van Tuyl, Francis M.**, THE MOTTLED TRIBES HILL LIMESTONE AND ITS BEARING ON THE ORIGIN OF DOLOMITES [Abstract], 378
- THE ORIGIN OF DOLOMITES [Abstract], 362
and **Fritz Berckhemmer**, A PROBLEMATIC FOSSIL FROM THE CATSKILL FORMATION [Abstract], 378
- VOLCANIC DUST VEILS AND CLIMATIC VARIATIONS, **Henryk Arctowski** [Abstract], 398
- Volger, G. H. O.**, References to, 27, 34
- von Huene, F.**, References to, 275, 276
- von Ihering, H. V.**, References to, 193, 197, 305, 315
- von Isakovics, Alois**, Fellow, 400

- Wachsmuth, C.**, Reference to, 15
Walcott, C. D., Reference to, 206
Wallace, Alfred Russell, References to, 179, 185, 187, 203, 205
Walton, Lillian, INDIVIDUAL DIFFERENCES IN JUDICIAL CAPACITY [Abstract], 375
Wang, Y. Tsenshan, Associate Member, 365
Warner, Mrs. H. W., Active Member, 396
Watzof, Spas, Reference to, 60
Weinschenk, E., cited, 28
Weissman, August, Death of, 397
Wetzel, Reinhard A., THE STARK EFFECT OR ELECTRIC RESOLUTION OF THE SPECTRA OF THE ELEMENTS [Title], 388
White, I. C., cited, 130
Wilckins, —, Reference to, 193
WILD TRIBES OF MINDANAO. THE. Fay Cooper Cole [Abstract], 352
Wille, N., SYMPOSIUM ON PORTO RICO [Abstract], 399
Williams, J. Leon, ON THE PILTDOWN AND OTHER PREHISTORIC SKULLS [Title], 349
Willis, Bailey, Reference to, 175
Wiman, —, Reference to, 193
Wintringham, J. P., Active Member, 396
Wood, Elvira, Fellow, 400
THE USE OF CRINOID ARMS IN STUDIES OF PHYLOGENY, 1-17
Woodman, J. Edmund, cited, 124
Reference to, 117
Woodworth, R. S., THE WORK CURVE FOR SHORT PERIODS OF INTENSE APPLICATION [Abstract], 360
WORK CURVE FOR SHORT PERIODS OF INTENSE APPLICATION, THE. **R. S. Woodworth** [Abstract], 360
Wortman, J. L., References to, 179, 197
Zittel, K. V., References to, 179, 284
Zoölogical regions, past and present, 185-189





